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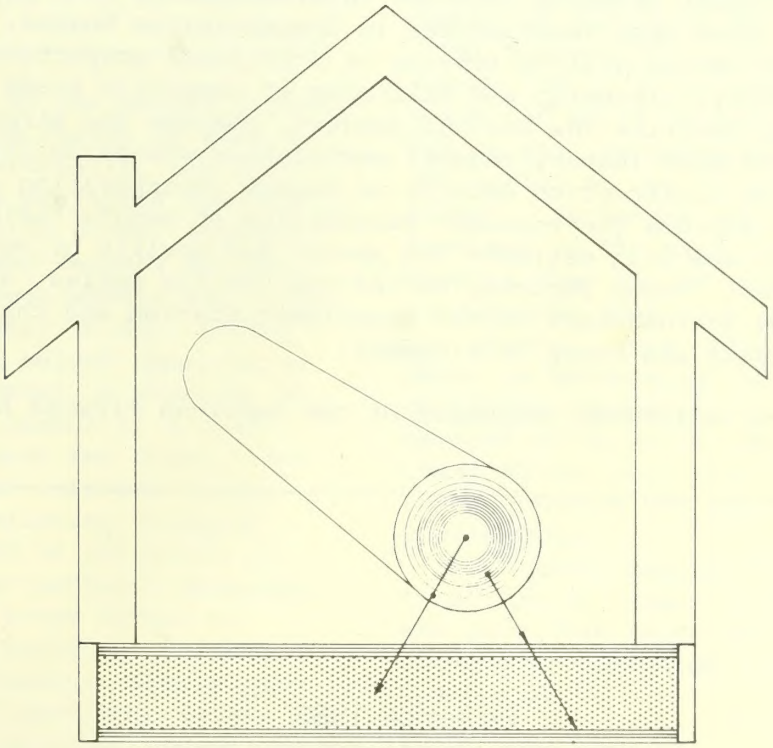
Veneer Yields by Grade From Three Coastal Plain Hardwoods — Blackgum, Sweetgum, and Yellow-Poplar

United States
Department of
Housing and
Urban Development

Robert H. McAlister and Alexander Clark III

Research Paper SE-238



COM-PLY® Report 24

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This report is one of a series on the possibilities of producing house framing and structural panels with flakeboard cores and veneer facings. These COM-PLY or composite materials were designed to be used interchangeably with conventional lumber and plywood in houses. Research on structural framing was initially limited to COM-PLY studs but has now been extended to include larger members such as floor joists and roof truss framing.

In 1973, the home-building industry faced a shortage of lumber and plywood and consequent rising prices. Both industry and government recognized that this situation was not a temporary problem and that long-range plans for better using the Nation's available forest resources would be necessary.

The Forest Service of the U.S. Department of Agriculture and the U.S. Department of Housing and Urban Development accelerated cooperative research on ways to utilize the whole tree. They concentrated on composite wood products made with flakeboard and veneer as a way of using not only more of the tree stem, but also using less desirable trees and a greater variety of tree species than would be used for conventional wood products. The flakeboard which constitutes a large portion of COM-PLY studs and joists, is made from flaked-up wood that comes from forest residues, mill residues, or low-quality timber. Thus, such composites could greatly increase the amount of lumber and plywood available for residential construction, our major use of wood, without eroding the Nation's timber supply.

Research on composite wall and floor framing was performed by the Wood Products Research Unit, Southeastern Forest Experiment Station, Athens, Ga. The American Plywood Association cooperated in these studies by designing and testing composite panel products that are interchangeable with plywood. Both types of products have been incorporated in demonstration houses.

Included in this series will be reports on structural properties, durability, dimensional stability, strength, and stiffness of composite studs and joists. Other reports will describe the overall project, compare the strength of composite and solid-wood lumber, suggest performance standards for composite lumber, and provide construction details on houses incorporating such lumber. Still others will explore the economic feasibility of manufacturing composite lumber and panels, and will estimate the amount and quality of veneer available from southern pines. These reports, called the COM-PLY series, will be available from the Southeastern Forest Experiment Station and the U.S. Department of Housing and Urban Development.

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Southeastern Forest Experiment Station
200 Weaver Blvd.
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Veneer Yields by Grade from Three Coastal Plain Hardwoods—Blackgum, Sweetgum, and Yellow-poplar

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Abstract

The dry volume and standard grades of veneer (PS-1-74) available from blackgum, sweetgum, and yellow-poplar from a Coastal Plain site are presented according to tree diameter class. Analyses of the yields of veneer and residues are made for the hardwood species and for mixed southern pine and hardwoods.

Keywords: Southern pine, diameter class, volume, blocks, residue, *Nyssa sylvatica, Liquidambar styraciflua, Liriodendron tulipifera.*

Nearly two-thirds of the annual timber harvest in the United States is used in construction. Traditionally, the construction market has preferred the softwood species--primarily pines, spruce, Douglas-fir, firs, and western hemlock. These species have been widely available and are relatively easy to dry, stable in use, and light in weight compared to many hardwoods. However, a shortage of commercial softwood timber is a real possibility in the next few years. The increasing demand for softwood timber is already creating a relative shortage (USDA FS 1973), which is reflected in increasing prices for softwood stumpage. Although there is a large volume of hardwood timber available, it is not fully utilized at present. Ninety percent of the hardwood sawtimber volume is found east of the Mississippi River (USDA FS 1978) close to the major construction markets. This hardwood resource must be used effectively if we are to meet future demands for construction lumber and panels at competitive prices. One method of hardwood utilization is in plywood or composite structural lumber.

Previous studies (McAlister 1979) have shown that composite lumber (COM-PLY) made from yellow-poplar (*Liriodendron tulipifera* L.), sweetgum (*Liquidambar styraciflua* L.), and white oak (*Quercus alba* L.) has structural properties comparable to COM-PLY lumber made from southern pine veneers. COM-PLY lumber made from both hardwood and softwood veneers compared favorably to dimension lumber of spruce or fir.

The concept of combining high-strength veneer (25 to 40 percent) with flakeboard (60 to 75 percent) made from forest or mill residues is well suited to the efficient use of available hardwood timber. Hardwoods and softwoods can be combined in the same composite product. Usually they can be combined in the same proportions that they occur in the timber stands. This offers potential economies in harvesting, manufacturing, and marketing composite lumber and panels. Removal of hardwoods and some low-grade trees would lower site preparation costs for replanting and improve resource utilization.

This report supplements published information on veneer yields from southern pine (McAlister and Taras 1978) and hardwoods (McAlister 1981) in the Southeast.

Procedures

Trees for this veneer-yield study were selected as part of a total tree (above-

ground) biomass study.[1] The site selected was the Honey Hill unit of the Francis Marion National Forest near McClellanville, S.C. The stand was located in a swampy area consisting of old rice fields. Sweetgum, yellow-poplar, and water oak were found in the better drained areas; blackgum (*Nyssa sylvatica* Marsh.) was found in poorly drained swamps with standing water. For each species, three trees were selected from each of the five even-inch (12, 14, ... 20) diameter classes from 12 to 20 inches diameter at breast height (d.b.h.). For example, the 14-inch d.b.h. class includes trees from 13.0 to 14.9 inches d.b.h. Within each diameter class we tried to sample the full range of diameters. The trees selected had no obvious defects such as lightning scars or visible decay, and were No. 1 or No. 2 sawtimber quality. The 12-inch trees were included although the top grades require a minimum d.b.h. of 13.0 inches.

Trees were felled and bucked into logs that were multiples of the 8.75-foot-long veneer blocks. Usually logs were cut to 17.5- or 26.3-foot lengths, which are easy to skid, handle, and load. Sample disks 1-inch thick were taken at each bucking cut. These disks were used to determine specific gravity, moisture content, bark thickness, and rate of growth along the stems.

More than half the water oak stems had severe butt rot extending from the stump upward 4 to 6 feet, so this species was eliminated from the veneer cutting phase.

Each log was weighed on a portable electronic scale. Logs were then trucked to a cooperating southern pine plywood plant and cut into peeler blocks 103 to 104 inches long. Each block was marked with the tree number and the block number in the stem (fig. 1). The end diameters of each block were recorded to the nearest 0.1 inch. All blocks were heated in 160°F water for 16 to 18 hours before peeling. The veneer lathe was set to produce veneer 1/6 inch thick (avg. 0.167). The peeler core diameter was recorded for each block. It averaged 5.4 inches.

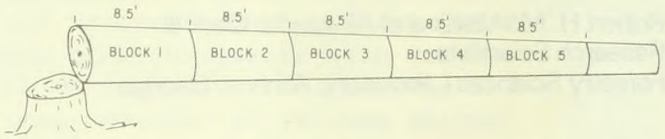

Figure 1.--Diagram of veneer blocks measured on stem.

Veneer from individual blocks was color-coded with stripes of water-soluble dye so that it could be related to the block from which it was peeled (Schroeder and Clark 1970). Veneer was clipped into full sheets, half sheets, and strips according to standard mill practice for softwood veneer-grade defect limitations. (This particular mill generally clipped to maximize the number of full sheets rather than to maximize grade. Also no strip less than 12 inches wide was saved.) The veneer was dried for 12 minutes at 385° F in a commercial four-deck steam-heated, jet-type veneer dryer to an average moisture content of less than 6 percent. Veneer was graded after drying as per softwood veneer grades (American Plywood Association 1974). Dry veneer volumes and grades were recorded for veneer 0.160 inch thick and for sizes as follows:

Full sheets	-- 50 by 102 inches
Half sheets	-- 26 by 102 inches
Strip	-- actual width by 102 inches
Fishtail	-- actual width by 54 inches

All strip and fishtail were graded as C- or D-grade veneer. Actual width for strip and fishtail ranged between 12 and 25 inches.

Results and Discussion

Summary data of veneer yields by species and grade are presented. The main body of the report contains data by tree diameter, species, and derived information for hardwood and mixed pine and hardwood stands on the South Carolina Coastal Plain. These data can be used

[1]Clark, Alexander, III. Multi-product weight volume factors and total tree weight and volume of the major southern hardwoods. Unpublished study plan on file at Southeastern Forest Experiment Station, Athens, Ga. 1977. 35 p.

to estimate yields of veneer, plywood, or composite products that could be produced from any given stand or mix of species available.

Table 1 shows veneer yield by grade for the three study species by diameter class. Yellow-poplar stems were taller and thus yielded more veneer blocks than sweetgum or blackgum. However, there is very little difference in green-block volume between yellow-poplar and sweetgum. There is very little difference in veneer recovery factors for the three species except for the 14-inch blackgum (low) and the 20-inch yellow-poplar (high). The small number of trees within each diameter class probably distorts some of the yield relationships.

Veneer yields by grade for the three species are also comparable for the C and better grades of veneer. Blackgum yields much less D-grade veneer than yellow-poplar or sweetgum. The principal use for the data in table 1 is in conjunction with timber stand cruise data or forest survey volume data to estimate the volume of veneer by grade that can be peeled from timber on a given stand.

For example, forest survey data (Craver 1978) is available for the South Carolina Coastal Plain. Table 13 of Craver's report shows the number of growing-stock trees by species and d.b.h. class on commercial forest land. Using Craver's report to obtain the percentage distribution of the three study species by diameter class, and table 1 for volume data, we can construct table 2. The data in table 2 assume that we will harvest only the three study species and ignore the pines, oaks, and soft maple which make up a significant volume of the stand. Table 2 is interesting in spite of these limitations.

Blackgum (and tupelo gum) makes up 56.7 percent of the total number of stems considered and 59.3 percent of the number of stems 16 inches d.b.h. and larger. This indicates that blackgum is probably an underutilized species. Blackgum yields 60 percent of the total C-grade and better veneer and only 30 percent of the D-grade veneer from the stand. Sweetgum makes up 39 percent of the tree volume, yields 29 percent of the C-grade and better volume and 60 percent of the D-grade veneer. Yellow-poplar makes up about 10 percent of tree volume and of total veneer volume.

The relationship between species and veneer grade is somewhat clearer in table 3, where volume for veneer blocks, trees, and residues is on an ovendry volume basis. Green volumes were reduced by the volumetric shrinkage de-

Table 1.--Average dry cubic feet of veneer by grade and diameter class in yellow-poplar, sweetgum, and blackgum from the Coastal Plain

Species	Tree d.b.h. (inches)	Tree ht. (ft)	No. veneer blocks	Dry veneer volume				Green block volume	Green tree volume	Average veneer recovery factor
				AB	C	D	Fishtail			
				Cubic feet						*Percent*
Yellow-poplar	12	65.8	3	0.22	2.56	0.77	0.50	11.18	23.79	32.8
	14	73.1	5	2.66	4.68	1.30	.56	2 .98	38.64	48.1
	16	76.1	6	.15	8.91	6.90	.56	34.23	46.61	48.1
	18	85.0	7	.44	12.94	3.90	1.75	41.35	59.98	42.4
	20	82.7	5	1.33	15.95	6.39	1.46	42.39	67.30	58.1
Sweetgum	12	59.2	3	.15	1.40	2.01	.20	12.07	23.74	3 .0
	14	72.0	5	.44	4.78	4.14	.80	27.05	38.64	35.3
	16	66.8	5	2.24	7.34	6.08	.91	33.82	49.59	47.9
	18	74.4	5	1.68	8.58	11.20	.76	42.20	64.18	52.6
	20	77.4	5	1.90	13.91	12.05	1.04	56.11	77.17	51.2
Blackgum	12	6 .2	3	.15	3.13	.39	.40	1 .46	22.55	35.9
	14	6 .3	4	.60	4.08	1.24	.50	16.36	28.33	3 .9
	16	67.2	4	1.19	1 .18	2.10	.70	32.44	44.63	42.5
	18	78.4	5	2.12	1 .62	3.21	1.12	36.58	61.02	45.2
	20	83.0	5	.00	12.80	3.61	2.06	37.26	66.24	45.7

Table 2.--Average veneer yields per 100 stems from a typical mixture of yellow-poplar, sweetgum, and blackgum from a natural Coastal Plain timber stand

Tree diameter class (inches)	Species	No. of stems	Dry veneer volume AB	C	D	Fish-tail	Green block volume	Green tree volume
			Cubic feet					
12	Yellow-poplar	2.3	0.5	5.9	1.8	1.2	25.7	54.7
	Sweetgum	16.7	2.5	23.4	33.6	3.3	201.6	396.5
	Blackgum	21.4	3.2	67.0	8.3	8.6	223.8	482.6
14	Yellow-poplar	2.2	5.9	10.3	2.9	1.2	46.2	85.0
	Sweetgum	9.4	4.1	44.9	38.9	7.5	253.3	362.2
	Blackgum	16.8	10.1	68.5	20.8	8.4	274.8	475.9
16	Yellow-poplar	1.2	.2	1 .7	8.3	0.7	41.4	55.9
	Sweetgum	5.5	12.3	40.4	33.4	5.0	186.0	272.8
	Blackgum	9.7	11.5	98.7	20.4	6.8	314.7	432.9
18	Yellow-poplar	1.1	.5	14.2	4.3	1.9	45.5	66.0
	Sweetgum	2.9	4.9	24.9	32.5	2.2	122.4	186.1
	Blackgum	5.7	12.1	60.5	18.3	6.4	208.5	347.8
20	Yellow-poplar	.6	1.5	17.5	7.0	1.6	46.6	40.4
	Sweetgum	1.4	2.7	19.5	16.9	1.5	73.6	180.0
	Blackgum	3.1	0	39.7	11.2	6.4	115.5	205.3
	Total	100.0	72.0	546.1	258.6	62.7	2184.3	3644.1
	Yellow-poplar	7.4	8.6	58.6	24.3	6.6	205.1	302.0
	Sweetgum	35.9	26.5	153.1	155.3	19.5	841.9	1397.6
	Blackgum	56.7	36.9	334.4	79.0	36.6	1137.3	1944.5

Table 3.--Average dry volume of veneer and residues from 100 stems of a typical mixture of yellow-poplar, sweetgum, and blackgum from a Coastal Plain hardwood stand in northern South Carolina

Item	Yellow-poplar	Sweet-gum	Black-gum	Total	Proportion of stand volume
	Cubic feet				*Percent*
A and B veneer	8.6	25.6	36.9	72.0	2
C veneer	58.6	153.1	334.4	546.1	17
D veneer	24.3	155.3	79.0	258.6	8
Total full-length veneer	91.5	334.9	450.3	876.7	27
Fishtail	6.6	19.5	36.6	62.7	2
Total veneer	98.1	354.4	486.9	939.4	29
Peeling residue	182.4	386.5	513.9	1982.8	31
Total block volume	180.5	740.9	1000.8	1922.2	60
Top log residue	85.3	489.0	710.4	1284.6	40
Total tree volume	265.8	1229.9	1711.2	3206.8	100

termined from the sample disks. (Volumetric shrinkage and other physical properties determined from disk samples are shown in table 4.) Note that the total volume of veneer recovered, 29 percent, was less than the volume of peeling residue, 31 percent. Also note that if the stem to a 4-inch top is taken out of the woods, there is a 40 percent increase in the total volume of wood material available. This is a significant source of residue suitable for uses such as pulpwood or fuelwood. About 70 percent of the veneer was of C and better grade. This is an excellent grade mix.

Table 5 is similar to table 2 except that southern pine is included in the volume data. Table 5 is constructed from the forest survey data (Craver 1978), pine veneer-yield data (McAlister and Taras 1978), and the hardwood volume data in table 1. Note that the 10-inch diameter class trees are included for the southern pine. Again the significant volume of oaks and soft maple is ignored.

Southern pine accounts for almost 28 percent of stems in the 10-inch d.b.h. class and 70 percent of total stems. It is obvious that when considering the mixed pine and hardwood volume, the pine volume is much greater. However, by including yellow-poplar, sweetgum, and blackgum, total wood volume harvested increased by almost 50 percent.

Table 6 shows the relationship between species and veneer grade for the mixed pine and hardwood stand. Note that the hardwood top-log residue, particularly the blackgum, contributes a tremendous volume of wood material to the total. In fact, blackgum makes up about 17 percent of the number of stems but yields 34 percent of the top-log residue volume. The southern pine yielded more veneer volume than peeling residue volume; the hardwoods less.

As an Appendix, information is given on veneer yields by block diameter (table 7) and a comparison of veneer yields for hardwoods from the three physiographic areas studied in the Southeast (table 8).

Table 4.--Selected physical properties of three Coastal Plain hardwoods

Physical property	Yellow-poplar	Sweetgum	Blackgum
Wood specific gravity $\left(\frac{\text{OD wt}}{\text{OD vol}}\right)$	0.42	0.47	0.48
Wood MC $\left(\frac{\text{G:W-OD wt} \times 100}{\text{OD wt}}\right)$ (%)	110	117	104
Volumetric shrinkage (Gri/OD) (%)	12.3	15.0	13.9
Bark specific gravity $\left(\frac{\text{OD wt}}{\text{OD vol}}\right)$	.36	.47	.43
Bark MC (%)	113	76	81
Weight of bark (percent of dry wood weight)	17	12	15

Table 5.--Average veneer yields by grade per 100 stems of mixed pine and hardwood, by species and tree d.b.h. class for typical timber stands in the northern Coastal Plain of South Carolina

Tree d.b.h. class (inches)	Species	No. of stems	Dry veneer volume				Green block volume	Green tree volume
			AB	C	D	Fish-tail		
			Cubic feet					
10	Pine	27.6	16.6	49.7	11.0	8.3	270.5	416.8
12	Pine	18.9	30.2	86.9	24.6	9.4	361.0	412.0
	Yellow-poplar	.8	.2	2.0	.6	.4	8.9	19.0
	Sweetgum	5.0	.8	7.0	10.0	1.0	60.4	118.7
	Blackgum	6.4	1.0	20.0	2.5	2.6	66.9	144.3
14	Pine	11.6	29.0	91.6	55.7	13.9	375.8	401.4
	Yellow-poplar	.7	1.9	3.3	.9	.4	14.7	27.0
	Sweetgum	2.8	1.2	13.4	11.6	2.2	75.7	108.2
	Blackgum	5.0	3.0	20.4	6.2	2.5	81.8	141.6
16	Pine	6.3	29.9	68.7	61.2	10.9	312.8	327.1
	Yellow-poplar	.4	.1	3.6	2.8	.2	13.7	18.6
	Sweetgum	1.6	3.6	11.7	9.7	1.5	54.1	79.3
	Blackgum	2.9	3.4	29.5	6.1	2.0	94.1	129.4
18	Pine	3.6	29.2	36.0	47.5	7.2	205.9	228.2
	Yellow-poplar	.3	.1	3.9	1.2	.5	12.4	18.0
	Sweetgum	.9	1.5	7.7	10.1	.7	38.0	57.8
	Blackgum	1.1	3.6	18.0	5.5	1.9	62.2	103.7
20	Pine	1.5	15.0	16.5	27.3	3.4	103.2	126.4
	Yellow-poplar	.2	.3	3.2	1.3	.3	8.5	11.6
	Sweetgum	.4	.8	5.6	4.8	.4	22.4	30.9
	Blackgum	1.5	0	11.5	3.2	1.8	33.5	59.6
	Total	100.0	171.4	509.3	303.8	71.5	2276.5	2979.6
	Pine	70.0	149.9	349.1	227.3	53.1	1629.2	1911.9
	Yellow-poplar	10.7	7.9	16.0	6.8	1.8	58.2	94.2
	Sweetgum	2.4	2.6	44.8	46.2	5.8	250.6	394.9
	Blackgum	16.9	11.0	99.4	23.5	10.8	338.5	578.6

Table 6.--Average dry volume of veneer and residues from 100 stems of mixed pine and hardwood for a typical timber stand in the northern Coastal Plain of South Carolina

Item	Pine	Yellow-poplar	Sweet-gum	Black-gum	Total	Proportion of stand (all species)	Total hardwood	Hardwood proportion of stand volume
	.....Cubic feet.....					Percent	Cubic feet	Percent
A and B veneer	149.9	2.7	7.9	11.0	171.5	7	21.6	1
C veneer	349.1	16.0	45.4	99.4	509.9	19	160.8	6
D veneer	227.3	6.8	46.2	23.5	303.8	12	76.5	3
Total full-length veneer	726.3	25.5	99.5	133.9	985.2	38	258.9	10
Fishtail	53.1	1.8	4.6	10.8	70.3	2	17.2	1
Total veneer	779.4	27.3	104.1	144.7	1055.5	40	276.1	11
Peeling residue	583.9	23.9	116.4	153.2	947.8	36	293.5	11
Total block volume	1433.7	51.2	220.5	297.9	2003.3	76	569.6	22
Top log residue	248.8	31.7	127.0	211.3	618.7	24	370.0	14
Total tree volume	1682.5	82.9	347.5	509.2	2622.0	100	939.6	36

Conclusions

The following conclusions may be drawn based from the data presented:

1. Yellow-poplar, sweetgum, and blackgum from the Coastal Plain give acceptable volume yields of veneer suitable for the manufacture of plywood or composite products.

2. Blackgum yields a high proportion of C and better grade veneer.

3. Although southern pine makes up more than two-thirds of the tree volume in Coastal Plain stands, the hardwoods can significantly increase the volume of veneer available when harvested and processed in conjunction with the pine.

Acknowledgment

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Table 7.--Average veneer yield by grade and block diameter class for yellow-poplar, sweetgum, and blackgum from the Coastal Plain

Block diameter (inches)	Dry veneer volume				Green block volume	Residue	Veneer recovery factor
	AB	C	D	Fish-tail			
	Cubic feet						*Percent*
			YELLOW-POPLAR				
9	0.15	0.61	0.38	0.18	4.26	3.12	26.7
10	0	.87	.91	.22	5.38	3.60	32.6
11	.39	1.37	.49	.14	6.05	3.80	36.8
12	.22	2.16	.94	.29	7.39	4.07	44.6
13	.19	2.04	2.15	.22	8.90	4.52	49.3
14	.06	3.65	1.63	.32	10.58	5.23	50.8
15	0	4.96	1.03	.30	11.40	5.41	53.0
16	1.00	6.45	1.02	.33	13.93	5.45	61.0
			SWEETGUM				
9	.0	.36	.79	.12	4.42	3.27	27.2
10	0	.52	1.09	.11	5.09	3.48	31.6
11	.06	.89	1.53	.18	6.36	3.88	38.5
12	.11	1.14	1.47	.15	7.44	4.72	36.4
13	.58	1.86	1.63	.17	8.53	4.46	47.5
14	.85	2.20	2.56	.19	10.24	4.63	55.4
15	.16	3.18	2.45	.24	11.59	5.81	50.0
16	.34	2.65	3.62	.33	12.92	6.32	51.2
17	1.19	6.00	1.58	.24	15.56	6.78	56.7
			BLACKGUM				
9	0	1.05	.55	.21	4.25	2.65	37.5
10	.18	1.49	.35	.17	5.44	3.43	37.5
11	.20	1.38	.45	.26	6.37	4.34	32.4
12	.22	1.99	1.10	.16	7.49	4.17	44.6
13	.72	2.96	.37	.22	9.78	5.73	43.1
14	.64	3.99	.43	.37	10.46	5.40	49.4
15	.22	5.57	.47	.38	13.57	7.31	46.8

Table 8.--Comparison of veneer yields by species and tree diameter class for three physiographic areas in the Southeast

Tree d.b.h. (inches)	Coastal Plain						Piedmont						Mountain					
	Dry veneer volume				Green block volume	Green tree volume	Dry veneer volume				Green block volume	Green tree volume	Dry veneer volume				Green block volume	Green tree volume
	AB	C	D	Fish-tail			AB	C	D	Fish-tail			AB	C	D	Fish-tail		
	Cubic feet																	
YELLOW-POPLAR																		
12	0.2	2.6	0.8	0.5	11.2	23.8	0.2	1.5	0.7	0.4	11.7	24.7	0	1.2	0.5	0.3	11.5	22.9
14	2.7	4.7	1.3	.6	21.0	38.6	0	6.4	2.6	.6	21.8	33.0	0	10.4	2.4	.8	31.8	44.0
16	.2	8.9	6.9	1.6	34.2	46.6	.2	10.1	3.9	1.3	34.0	45.4	0	15.5	10.4	1.3	51.8	57.9
18	.4	12.9	3.9	1.8	41.4	60.0	.5	15.3	7.7	1.4	52.6	61.5	0	16.4	12.8	2.5	64.8	77.4
20	1.3	16.0	6.4	1.5	42.4	67.3	1.9	14.5	9.1	1.4	56.5	73.4	0	18.3	18.8	1.7	76.9	96.8
SWEETGUM																		
12	.2	1.4	2.0	.2	12.1	23.7	.2	2.2	.3	.3	7.0	19.3	--	--	--	--	--	--
14	.4	4.8	4.1	.8	27.0	38.6	.9	8.4	1.9	.9	24.2	34.4	--	--	--	--	--	--
16	2.2	7.3	6.1	.9	33.8	49.6	.2	5.9	4.5	1.4	31.9	42.8	--	--	--	--	--	--
18	1.7	8.6	11.2	.8	42.2	64.2	1.1	9.8	4.1	1.3	35.7	53.8	--	--	--	--	--	--
20	1.9	13.9	12.0	1.0	56.1	77.2	1.3	10.7	11.1	1.6	48.5	66.9	--	--	--	--	--	--
WHITE OAK																		
12	--	--	--	--	--	--	0	.7	.5	.4	8.7	17.9	0	1.8	1.7	.8	16.9	23.5
14	--	--	--	--	--	--	0	2.2	2.4	.6	15.7	28.6	0	2.3	5.3	.8	28.5	36.2
16	--	--	--	--	--	--	0	3.2	5.3	1.2	27.6	41.9	0	3.4	8.4	.8	38.6	45.8
18	--	--	--	--	--	--	0	3.4	8.8	1.3	35.0	52.4	0	2.4	12.5	.6	40.8	66.6
20	--	--	--	--	--	--	0	5.9	9.0	.8	40.5	68.9	0	4.9	12.2	1.7	44.3	69.3
BLACKGUM																		
12	.2	3.1	.4	.4	10.5	22.6	--	--	--	--	--	--	--	--	--	--	--	--
14	.6	4.1	1.2	.5	16.4	28.3	--	--	--	--	--	--	--	--	--	--	--	--
16	1.2	10.2	2.1	.7	32.4	44.6	--	--	--	--	--	--	--	--	--	--	--	--
18	2.1	10.6	3.2	1.1	36.6	61.0	--	--	--	--	--	--	--	--	--	--	--	--
20	0	12.8	3.6	2.1	37.3	66.2	--	--	--	--	--	--	--	--	--	--	--	--

McAlister, Robert H.; Clark, Alexander, III
Veneer yields by grade from three Coastal Plain hardwoods--blackgum, sweetgum, and yellow-poplar. Res. Pap. SE-238. COMPLY Rep. 24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station and Washington, DC: U.S. Department of Housing and Urban Development; 1983. 12 p.

Data presented can be used to estimate yields of veneer, plywood, or composite products that could be produced from any given stand or mix of species available.

Keywords: Southern pine, diameter class, volume, blocks, residue, *Nyssa sylvatica*, *Liquidambar styraciflua*, *Liriodendron tulipifera*.

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Research Paper SE-239

Effect of Veneer Grade on Bending and Compression of COM-PLY Truss Lumber

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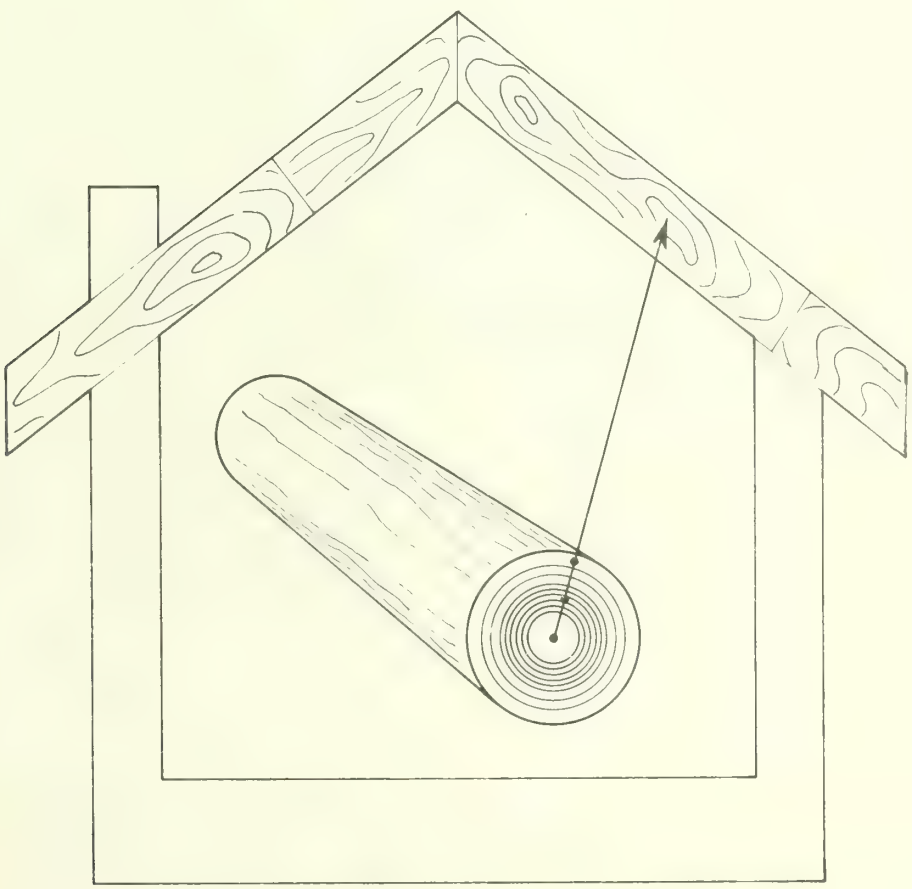
Robert H. McAlister



COM-PLY® Report 25

This report is one of a series on the possibilities of producing house framing and structural panels with flakeboard cores and veneer facings. These COM-PLY or composite materials were designed to be used interchangeably with conventional lumber and plywood in housing. Research on structural framing was initially limited to COM-PLY studs but has now been extended to include larger members such as floor joists and roof truss framing.

In 1973, the home-building industry faced a shortage of lumber and plywood and consequent rising prices. Both industry and government recognized that this was not a temporary problem and that long-range plans for better using the Nation's available forest resources would be necessary.

The Forest Service of the U.S. Department of Agriculture and the U.S. Department of Housing and Urban Development accelerated cooperative research on ways to utilize the whole tree. They concentrated on composite wood products made with flakeboard and veneer as a way of using not only more of the tree stem, but also using less desirable trees and a greater variety of tree species than would be used for conventional wood products. The flakeboard which constitutes a large portion of COM-PLY studs and joists is made from flaked-up wood that comes from forest residues, mill residues, or low-quality timber. Thus, such composites could greatly increase the amount of lumber and plywood available for residential construction, our major use of wood, without eroding the Nation's timber supply.

Research on composite wall and floor framing was performed by the Wood Products Research Unit, Southeastern Forest Experiment Station, Athens, Ga. The American Plywood Association cooperated in these studies by designing and testing composite panel products that are interchangeable with plywood. Both types of products have been incorporated in demonstration houses.

Included in this series will be reports on structural properties, durability, dimensional stability, strength, and stiffness of composite studs and joists. Other reports will describe the overall project, compare the strength of composite and solid-wood lumber, suggest performance standards for composite lumber, and provide construction details on houses incorporating such lumber. Still others will explore the economic feasibility of manufacturing composite lumber and panels and estimate the amount and quality of veneer available from southern pines. These reports, called the COM-PLY series, will be available from the Southeastern Forest Experiment Station and the U.S. Department of Housing and Urban Development.

COM-PLY® is a registered trademark of the American Plywood Association.

August 1983

Southeastern Forest Experiment Station
200 Weaver Blvd.
Asheville, North Carolina 28804

Effect of Veneer Grade on Bending and Compression of COM-PLY Truss Lumber

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Abstract

COM-PLY truss lumber made with veneer of a variety of grades and grade combinations was tested in bending and compression. Allowable design stresses in bending and compression were found to be equivalent to No. 2 southern pine dimension lumber except for material made entirely of D grade veneer.

Keywords: MOE, MOR, F_c, F_b, southern pine.

Fabrication of light-frame wood trusses is an important part of the construction industry. In a "normal" year of approximately 1.4 million housing starts, more than 2 billion board feet of lumber is used in the manufacture of trusses (Kallio and Galligan 1979). Essentially all the lumber used in the manufacture of trusses is either visually stress graded or machine stress rated. Most of the lumber used is either Douglas-fir or southern pine. Some 76 percent of the lumber volume is nominal 2 x 4's.

Trusses are a highly engineered product. Unfortunately, sawed lumber--even stress-graded material--is not a uniform material. A structural composite with uniform strength properties for use in trusses would represent an important technological breakthrough for the truss industry. COM-PLY truss lumber is just such a material. COM-PLY truss lumber approximately 1.5 inches thick consists of two layers of 1/6-inch veneer laminated to each side of a 7/8-inch-thick oriented flakeboard core. The particle orientation of the flakeboard is parallel to the grain of the veneer.

Preliminary tests of COM-PLY truss lumber made with C and better grade southern pine veneer showed that it has excellent fastener-holding properties, strength, stiffness, and is uniform in properties with a coefficient of variation of about 10 percent.

COM-PLY truss lumber is about 42 percent veneer. Previous veneer-grade yield studies (McAlister and Taras 1978) show that about 30 percent of the southern pine tree volume is C grade and better veneer. In order to fully utilize the resource, we need to use most of the D grade veneer in the manufacture of COM-PLY truss lumber. Calculations show that if one of the four veneer plies is of D grade veneer with the other three of C and better grade, almost complete utilization of the resource is possible.

The objectives of this study were to determine the effect of veneer grade and combinations of veneer grade on (1) bending strength and stiffness and (2) compressive strength and stiffness of COM-PLY truss lumber, and (3) to determine the allowable design load in bending (F_b) and compression (F_c) for COM-PLY truss lumber.

Materials and Procedures

Materials

All tests were conducted on nominal 2- x 4- (1.5 x 3.5) inch COM-PLY truss lumber. All veneer used in this study was southern pine obtained from regular production of softwood plywood plants in Georgia and South Carolina, and graded according to commercial standards for softwood plywood (PS 1-74) (Am. Plywood Assoc. 1974).

Veneer-grade combinations used in this study (matched on each side of the flake board core) were: (1) B-B, (2) B-C, (3) B-D, (4) C-C, (5) C-D, and (6) D-D. When two grades of veneer were used, the

highest grade material was on the outer surface. Study veneer selected from stock was representative of the veneer defects permitted in each grade. A reference corner on each veneer sheet was used to maintain orientation throughout processing. Each veneer sheet, with a reference scale attached, was photographed before fabrication so that defect size and orientation could be determined precisely.

Veneer sheets (24 x 96 inches) were laminated with phenol-resorcinol adhesive that set at room temperature. The adhesive was single spread at a rate of 60 pounds per 1,000 square feet of glueline. Closed assembly time was 20 minutes. Pressure was applied at 100 psi in a cold press. The assemblies were cured for 20 hours at 70° F.

The flakeboard core used in this study was a fully oriented homogeneous panel made by Georgia-Pacific Corporation. The furnish was southern pine flakes 0.030 inch thick by 1.6 inches long. Phenolic-resin binder was used at the rate of 6 percent resin solids with 1 percent wax. The density averaged 39 pounds per cubic foot. The flakeboard was 7/16 inch thick, so two layers were laminated to provide the required 7/8-inch core thickness. Gluing procedures were the same as used to laminate the veneer layers.

COM-PLY truss lumber was fabricated as 24- x 96- x 1.5-inch blanks. The veneer and the core were glued together with a phenol-resorcinol adhesive by the same procedures used to laminate the veneers and the core. The blanks were precision ripped into 3.5-inch-wide test pieces. Care was taken to preserve the orientation of the veneer faces so that the defect pattern of the hidden plies could be reconstructed. Each blank yielded six 2 x 4's. The first 5 pieces from each blank were used in this study for a total of 10 samples of each veneer-grade group. The remaining pieces were reserved for another study.

Testing

Static bending. The 2 x 4's were tested over a 90-inch span with quarter-point loading. The deflections were measured at midspan with a dial micrometer mounted on a yoke. Deflections were taken at 100-pound-load increments until the total deflection exceeded 0.5 inch. Load rate was maintained at 300 pounds per minute. The yoke was then removed and the test continued to failure. Deflection under load, maximum load, location and type of failure, and time to failure were recorded for each beam.

Compression parallel to grain. Four 8-inch-long samples were cut from the undamaged sections of each static bending test sample. These blocks were loaded in compression at a rate of 2,000 pounds per minute. Deformations were taken at 2,000-pound-load increments to the nearest 0.0001 inch over a gage length of 6 inches. Deformation under load, maximum load, type and location of failure, and time to failure were recorded for each block.

Results and Discussion

Static Bending

Data for static bending tests were summarized by veneer-grade groups and based on actual dimensions (table 1). Note that the modulus of elasticity (MOE) is very uniform for all groups, with a range of 1.04 to 1.17 million psi, and quite uniform within groups and overall. The standard deviation of the combined data is only slightly higher than the group standard deviations.

The modulus of rupture (MOR) values show a definite trend downward as the veneer quality drops. The groups that include B grade veneer have somewhat higher MOR values than those with only C and D grade veneers. To assess significant differences among groups, Duncan's multiple range test (DMRT) was performed on the MOR data. The DMRT shows that there is no significant difference among the B-B, B-C, and B-D groups. This means that at the 95 percent probability level, the expected range of the means for the groups, is not different. There is also no significant difference among the B-D, C-C, C-D, and D-D groups. However, the B-B and B-C group averages are significantly higher than those of the C-C, C-D, and D-D groups.

The most important measure of strength for structural lumber used in trusses is the allowable design load for the extreme fiber in bending or F_b. The F_b values are shown in table 1. The groups with

some B grade veneer have F_b values greater than 1,600 psi. The group with the lowest quality veneers, D-D, has an F_b of only 1,151 psi. The combined F_b of all groups is 1,394 psi, which is roughly equivalent to the published value, 1,400 psi (SPIB 1977), for dry No. 2 southern pine light structural framing. However, the southern pine lumber has a higher MOE (1.6×10^6 psi). Since truss design is based more on strength than on stiffness, COM-PLY truss lumber appears to have sufficient bending strength for use in light-frame trusses. It would desirable to exclude the D-D material from production.

Compression Parallel to Grain

Data for compression tests were summarized by veneer-grade groups; values are based on actual dimensions at time of test (table 2). The compressive MOE was somewhat higher than the bending MOE (table 1), averaging about 1.4 million psi compared with 1.09 million psi. This difference between measures of MOE has been noted in previous research on structural composites (McAlister 1978).

The values for MOE, stress at proportional limit, and ultimate stress show a declining trend with decreasing veneer quality. It should be noted that the D-D group with the lowest quality veneer reversed this trend.

A DMRT was run on data for ultimate load compressive stress. This analysis showed that there was no significant difference in the average ultimate stress for groups B-D, C-C, and D-D. The B-B, B-C, and C-D group averages were significantly different from each other and all other groups. This indicates no consistent differences in compressive strength due to veneer grade.

The allowable design load in compression, F_c, is also shown in table 2. The values for the COM-PLY truss lumber are very high--equivalent to the published values (1,800 psi) for southern pine select structural KD grade (SPIB 1977).

It was noted that there appeared to be a relationship between F_c and MOE. A least-squares regression equation was determined to be: $F_c = 538.6 + 1{,}011(\text{MOE}) \times 10^{-6}$. This regression has a coefficient of determination (r^2) of 0.60, which means that 60 percent of the variation in F_c can be accounted for by variations in MOE.

Table 1.--Summary of static bending tests of 2 x 4 COM-PLY truss lumber made with southern pine veneer of different grades

Veneer-grade group	Modulus of elasticity		Modulus of rupture		Allowable design load
	Average	SD	Average[1]	SD	F_b[2]
	$\times 10^6$ psi		psi		
B-B	1.09	0.064	5,171[a]	819	1,748
B-C	1.17	.053	4,614[a]	323	1,915
B-D	1.08	.057	4,406[ab]	562	1,608
C-C	1.06	.044	3,827[b]	600	1,299
C-D	1.04	.047	3,852[b]	506	1,393
D-D	1.09	.059	3,602[b]	646	1,151
All groups combined	1.09	.066	4,245	789	1,394

[1] Values followed by the same letter are not significantly different at 0.05 level, based on Duncan's multiple range test.

[2] $F_b = \dfrac{\text{Avg. MOR} - t_{0.05}\,(\text{SD})}{2.1}$

Table 2.--Summary of compression parallel to grain tests of 2 x 4 COM-PLY truss lumber made with southern pine veneer of different grades

Veneer-grade group	Modulus of elasticity		Stress at proportional limit		Ultimate stress		Allowable design load
	Average	SD	Average[1]	SD	Average[1]	SD	F_c[2]
	....$x10^6$ psi...		.....psi.....				
B-B	1.52	0.25	3,287	606	4,845	550	2,062
B-C	1.48	.22	3,258	596	4,555	292	2,139
B-D	1.36	.20	2,740	562	4,004	375	1,927
C-C	1.36	.26	2,975	598	4,139	289	1,970
C-D	1.33	.27	2,558	627	3,983	337	1,798
D-D	1.53	.36	2,824	618	4,348[a]	315	2,009

[1]Values followed by the same letter are not significantly different at 0.05 level, based on Duncan's multiple range test.

[2]$F_c = \frac{\text{Avg. ultimate stress} - t_{0.05}\,(SD)}{1.9}$

Conclusions

COM-PLY truss lumber made with southern pine veneers of all grade combinations, except all D grade veneer, appears to be suitable for use in light-frame wood trusses based on bending and compressive strength and stiffness. Allowable design values are comparable to southern pine No. 2 grade material or better.

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Among veneer grades and grade combinations, except grade D alone, allowable design stresses in bending and compression were found to be equivalent to No. 2 southern pine dimension lumber.

KEYWORDS: MOE, MOR, F_c, F_b, southern pine.

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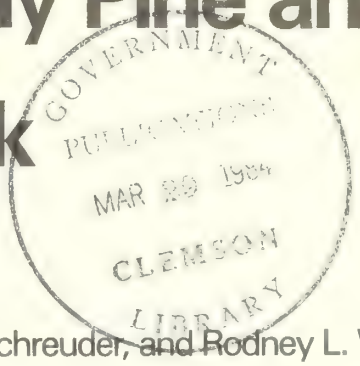
Research Paper
SE-240

A Comparison of Several Volume Table Equations for Loblolly Pine and White Oak



Joe P. McClure, Hans T. Schreuder, and Rodney L. Wilson

$V_i = \alpha_1 + \beta_1 X_i + e_{1i}$, $V(e_{1i}) = \sigma_1^2 X_i^{k2}$, $Ee_{1i} = 0$, $Cov(e_{1i}, e_{1j}) = 0$ for all $i \neq j$, (3)

$V_i = \alpha_1 + \beta_1 X_i + e_{2i}$, $V(e_{2i}) = \sigma_2^2 X_i^{k3}$, $Ee_{2i} = 0$, $Cov(e_{2i}, e_{2j}) = 0$ for all $i \neq j$; (4)

the logarithmic regression model

$\ln V_i = \alpha_3 + \beta_3 \ln X_i + e_{3i}$, $V(e_{3i}) = \sigma_3^2$, $Ee_{3i} = 0$, $Cov(e_{3i}, e_{3j}) = 0$ for all $i \neq j$; (5)

and the robust regressions

$V_i = \alpha_4 + \beta_4 X_i + e_{4i}$,
using Huber weighting (Schreuder and others 1979) (6)

$V_i = \alpha_5 + \beta_5 X_i + e_{5i}$,
using Hampel weighting (Schreuder and others 1979) (7)

where V_i = volume of tree i in cubic feet, X_i = diameter breast height (outside bark) in inches squared times the total height of tree i in feet, α_j and β_j ($j = 1, \ldots, 7$) are estimable constants, e_{ji} ($j = 1, \ldots, 7$) are errors with properties as described, and k_1, k_2, k_3 are estimated using the procedure below. Plottings of the data are given in figure 1 for the loblolly and in figure 2 for the white oak data.

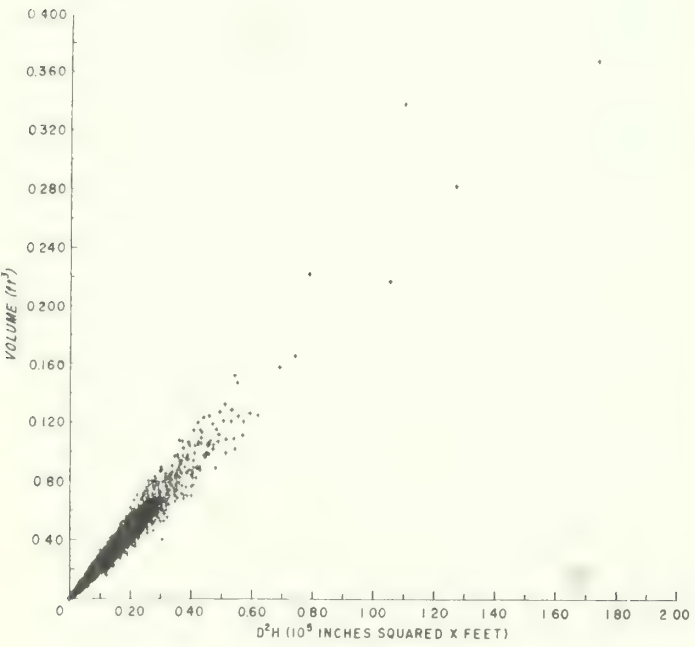


Figure 1. – Loblolly pine data plotting (n = 5,134).

Models were fit by minimizing residuals according to the specifications of the models. To obtain prior estimates of k_1, k_2, and k_3 for models 2, 3, and 4, the data were divided into equal-size D^2H classes. D^2H class ranges of 1,000 for loblolly pine and 500 for white oak were selected. The variance of V within each class was computed. The sample plotting for the entire loblolly pine data set, with a minimum of 30 observations per class, shows that the variance of V increases with increasing D^2H (fig. 3). The least squares model $\ln \text{Var}(V) = a + k \ln D^2H$ was fit (table 1). We obtained $k = 1.5$ for both loblolly and white oak by using, respectively, 55 classes with a minimum of 25 observations per class and 38 classes with a minimum of 12 observations per class. The minimum values of 25 and 12 observations per class were subjectively chosen from plottings. These values yielded rather smooth well-defined relationships between Var (V) and D^2H. The values $k_1 = 1.0$, $k_2 = 1.5$, and $k_3 = 2.0$ were used in models (2), (3), and (4), respectively, because such simple rounded values simplify estimation of α and β in model-based sampling (Schreuder, In press) and allow some check on the sensitivity of the results to differences in k values.

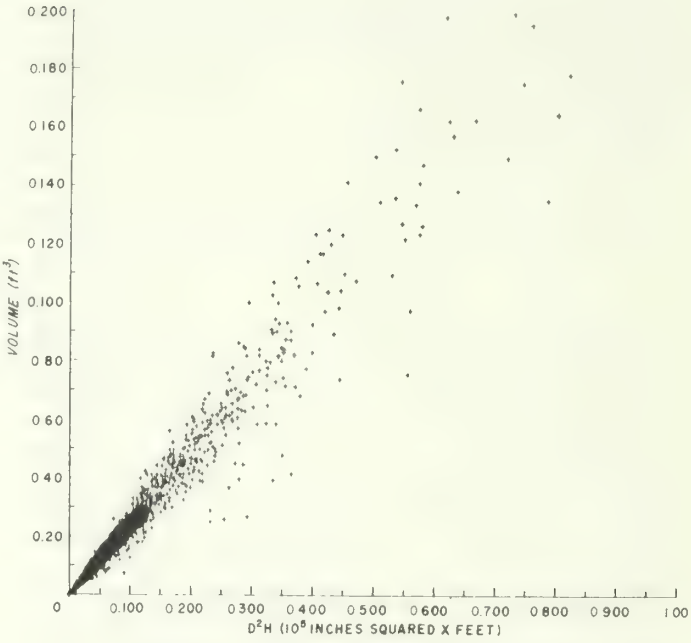


Figure 2. – White oak data plotting (n = 1,484).

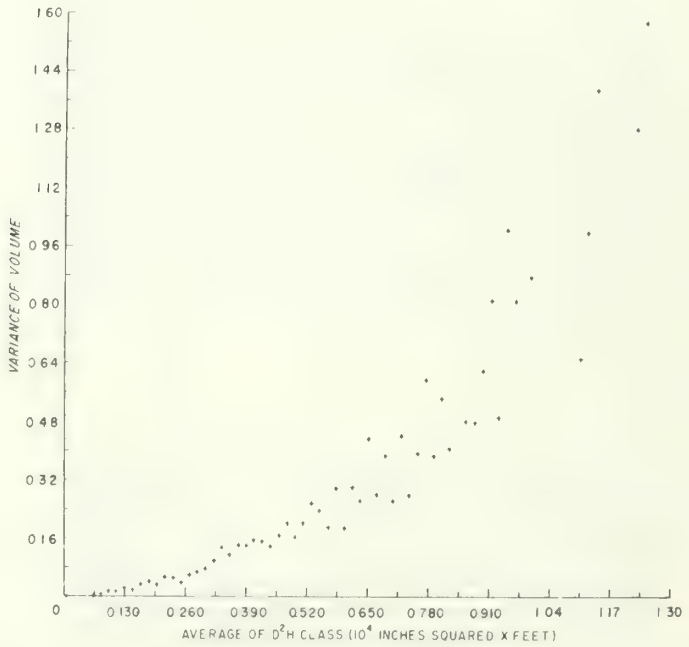


Figure 3. – Variance of volume within a D^2H class vs. the average D^2H of the class for 59 classes, with a minimum of 30 trees per class, for loblolly pine data.

Major criteria for comparing the models included R^2, likelihood, sum of deviations, sum of deviations squared, and sum of absolute deviations.

In addition, the assumption of a normal distribution for volume, by classes of the independent variable, was examined for the model deemed best. Also, the precision of confidence limits set by standard procedures was tested for the various models with different sample sizes under the assumption that the model deemed best was the true model.

Table 1. — Coefficients of the model ln variance (V) = a + k $\ln D^2H$ for groupings of D^2H by increments of 1,000 (in^2 x ft) considering only classes with at least the number of observations indicated for loblolly pine and white oak data

Minimum sample size	Number of classes	a	k	R^2	MSE
		Loblolly Pine			
15	89	-12.9	1.61	0.937	0.1691
20	70	-12.6	1.57	0.937	0.1431
25	55	-12.2	1.52	0.923	0.1601
30	44	-11.9	1.47	0.920	0.1626
40	31	-10.6	1.31	0.913	0.1391
50	19	- 9.3	1.13	0.909	0.1222
75	11	-11.5	1.40	0.849	0.0438
		White Oak			
10	48	-12.36	1.56	0.863	0.3180
12	38	-11.78	1.48	0.871	0.2875
14	28	-10.83	1.35	0.850	0.2683
16	24	-10.29	1.27	0.849	0.2498
18	19	-10.56	1.32	0.891	0.2166
20	17	-10.40	1.30	0.889	0.2290

Because of the much smaller data set available for white oak, a narrower and more intensive range of minimum sample sizes was considered than for loblolly pine.

Results and Discussion

Table 2 shows the regression equations for the seven models for both data sets. Since there are no really wild data points and because both data sets are large, the coefficients for the robust regression models (6) and (7) are similar to those from the weighted regression results of models (2), (3), and (4). For the loblolly pine the simple least squares regression model (1) and the robust regression models have large negative intercepts, whereas the intercepts for models (2), (3), and (4) are much closer to 0. For the white oak the robust regression models have relatively large negative intercepts, compared to other comparable models. Since volumes can be larger than 0 for $D^2H = 0$, a small positive intercept should be expected. The intercept for the log-log model (5) cannot be directly compared to the others since it estimates something else.

For d.b.h. = 0 and assuming a conical shape with radius r and height h, the volume of a cone is $1.047r^2h/144 = 0.0327r^2$ for a tree 4.5 feet high. If a 2-inch diameter at the base is assumed, volume is 0.0327 cubic feet. Hence, the intercept values for models (3) and (4) for the loblolly and for models (2), (3), and (4) for the white oak seem plausible, whereas those for models (1), (2), (6), and (7) for loblolly and models (1), (6), and (7) for white oak are not always reasonable. Model (5) coefficients can be compared less readily to those of the other models. Transforming the results back to the original scale yields $V = 0.0022\ X^{1.0019}$ for loblolly and $V = 0.0029\ X^{0.9798}$ for white oak. Both exponents are close to 1, as they should be, but it is clear that model (5) does not allow for a positive value of volume when $D^2H = 0$. Models (3) and (4) seem to describe the real world best in terms of what we know at present.

Table 2. — Volume table equations for loblolly pine (4,134 trees) and white oak (984 trees)

Model	Equation	Variance structure
	Loblolly Pine	
(1)	$V_i = -0.1675 + 0.002338\ X_i$	$V(e_{1i}) = \sigma_1^2$
(2)	$V_i = -0.0490 + 0.002324\ X_i$	$V(e_{2i}) = \sigma_2^2 X_i$
(3)	$V_i = 0.0222 + 0.002300\ X_i$	$V(e_{3i}) = \sigma_3^2 X_i^{1.5}$
(4)	$V_i = 0.0299 + 0.002276\ X_i$	$V(e_{4i}) = \sigma_4^2 X_i^2$
(5)	$\ln V_i = -6.1039 + 1.00189 \ln X_i$	$V(e_{5i}) = \sigma_5^2$
(6)	$V_i = -0.1772 + 0.002331\ X_i$	
(7)	$V_i = -0.1890 + 0.002331\ X_i$	
	White Oak	
(1)	$V_i = 0.0899 + 0.002380\ X_i$	$V(e_{1i}) = \sigma_1^2$
(2)	$V_i = 0.0369 + 0.002385\ X_i$	$V(e_{2i}) = \sigma_2^2 X_i$
(3)	$V_i = 0.0344 + 0.002386\ X_i$	$V(e_{3i}) = \sigma_3^2 X_i^{1.5}$
(4)	$V_i = 0.0346 + 0.002386\ X_i$	$V(e_{4i}) = \sigma_4^2 X_i^2$
(5)	$\ln V_i = -5.8679 + 0.9798 \ln X_i$	$V(e_{5i}) = \sigma_5^2$
(6)	$V_i = -0.0574 + 0.002414\ X_i$	
(7)	$V_i = -0.0783 + 0.002419\ X_i$	

Table 3 compares the seven models in terms of R^2, log likelihood ($\ln L$), sum of deviations (D_e), sum of deviations squared (D_e^2), and sum of absolute deviations ($|D_e|$). Although models (6) and (7) were derived for a special error structure, their main advantage is that they are supposed to yield good results when data deviate from assumptions required for simple least squares models (1). Hence, the likelihood criterion ($\ln L$) is not appropriate and is also difficult to calculate for models (6) and (7).

The results are not consistent. In terms of R^2, the robust regression models (6) and (7) are best. This result is not surprising since these models generally give the very largest devia-

tions less weight than the other deviations. R^2 values for models (2), (3), (4), and (5) are closely grouped. Model (1), the simple least squares model, clearly looks poorer than the rest.

Table 3. — Comparison of volume table equations for loblolly pine (4,134 trees) and white oak (984 trees) data under various criteria

Model	R^2	ℓn L	D_e	$\lvert D_e \rvert$	D_e^2
		Loblolly Pine			
(1)	0.9729	-11,333	0	8,370	58,195
(2)	0.9857	-8,641	0	8,385	58,259
(3)	0.9845	-7,989	619	8,398	58,820
(4)	0.9807	-8,141	1,517	8,442	60,223
(5)	0.9851	-8,137	799	8,387	58,854
(6)	0.9912	NA	275	8,362	58,228
(7)	0.9919	NA	331	8,361	58,237
		White Oak			
(1)	0.9481	-3,229	0	3,003	40,730
(2)	0.9737	-2,484	0	3,002	40,733
(3)	0.9761	-2,232	-9	3,001	40,735
(4)	0.9781	-2,127	-13	3,001	40,736
(5)	0.9786	-2,245	278	3,039	41,513
(6)	0.9916	NA	-200	2,993	40,925
(7)	0.9932	NA	-236	2,993	40,994

NA = not available.

In terms of the likelihood criterion (ℓn L), which measures the logarithm of the probability of the assumed model given the data, the simple least squares model (1) again is quite poor. Weighted regression models (3) and (4) and the log-log model (5) look about equally good, and the weighted regression model (2) is clearly poorer.

For the sum of the deviations (D_e) and deviations squared (D_e^2), the simple least squares model (1) is best, as expected, since the coefficients α and β are picked so as to minimize D_e^2 and make $D_e = 0$. Weighted regression model (2) also gives $D_e = 0$ but has slightly larger values for D_e^2 than does model (1). The weighted regression models (3), (4), and (5) perform well using D_e^2 as criterion and do well with D_e for the white oak, but models (3) and (4) are rather poor with D_e for the loblolly pine. The log-log model (5) does quite poorly with both D_e and D_e^2 for both species. The robust regression models (6) and (7) are only slightly better than the log-log model (5) with D_e for both species and with D_e^2 for white oak but perform similarly to the weighted regressions for the loblolly pine. The absolute deviation criterion ($|D_e|$) is not very useful for evaluation; it appears to differ little among models.

To allow for more sensitive testing, D_e, $|D_e|$, and D_e^2 were also computed by diameter size classes. Size classes selected correspond to traditional product classes for these species in the South and are $D < 5''$, $5'' \leq D < 9''$, and $D \geq 9''$ for loblolly and $D < 5''$, $5'' \leq D < 11''$ and $D \geq 11''$ for white oak. These results are shown in tables 4 and 5, respectively, for loblolly pine and white oak. These results show that the robust regression models (6) and (7) do poorly for the small trees for all three criteria, do rather well on the medium-size trees, and are about average on the large trees. This seems reasonable since robust regressions give relatively low weights to large residuals, which are more likely to occur at the extremes. The simple linear model, which gives considerable weight to large residuals, performs more or less as expected. It yields good results for large trees, average results for medium trees, good results for small white oak trees, but poor results for small loblolly pines. The weighted regressions give very inconsistent results. The most striking inconsistency is for medium-size trees where model (3) is best for white oak with D_e^2 but poorest for loblolly pine with the same criterion.

Table 4. — Comparison of volume table equations for loblolly pine data under various criteria for several diameter size classes, by size class (inches) and sample size (number)

Model	D_e	$\lvert D_e \rvert$	D_e^2
	$1 < D < 5$ (127)		
(1)	18.38	24.71	6.02
(2)	4.02	16.37	3.38
(3)	-3.75	13.45	3.19
(4)	-3.44	13.01	3.01
(5)	-0.10	13.69	2.99
(6)	19.93	25.71	6.44
(7)	21.45	26.80	6.93
	$5 \leq D < 9$ (1,592)		
(1)	-107.13	942.70	1,043.95
(2)	-245.55	967.69	1,074.29
(3)	-265.36	975.23	1,081.85
(4)	-182.39	959.42	1,062.19
(5)	-193.37	958.49	1,061.52
(6)	-67.64	939.02	1,039.38
(7)	-48.08	937.82	1,037.95
	$D \geq 9$ (2,415)		
(1)	88.60	7,403.01	57,144.7
(2)	241.43	7,401.07	57,181.8
(3)	888.16	7,409.80	57,734.5
(4)	1,703.08	7,469.64	59,158.0
(5)	992.33	7,414.46	57,789.4
(6)	322.79	7,397.38	57,182.1
(7)	357.20	7,396.78	57,192.0

Table 5. — Comparison of volume table equations for white oak data set, by size class (inches) and sample size (number)

Model	D_e	$\lvert D_e \rvert$	D_e^2
	1 < D < 5 (22)		
(1)	0.148	1.90	0.357
(2)	1.287	1.57	0.427
(3)	1.338	1.58	0.432
(4)	1.331	1.58	0.431
(5)	1.264	1.47	0.338
(6)	3.216	3.22	0.798
(7)	3.648	3.65	0.929
	5 ≤ D < 11 (521)		
(1)	-15.41	450.52	862.2
(2)	2.99	450.84	862.0
(3)	2.35	450.77	862.0
(4)	1.48	450.71	862.0
(5)	-58.05	449.89	866.7
(6)	0.57	449.94	864.6
(7)	1.61	449.97	865.5
	D ≥ 11 (441)		
(1)	15.29	2,550.7	39,867.1
(2)	-4.31	2,549.3	39,870.8
(3)	-12.47	2,548.8	39,872.5
(4)	-16.14	2,548.5	39,873.4
(5)	335.07	2,587.8	40,646.0
(6)	-204.08	2,540.0	40,059.1
(7)	-240.96	2,539.5	40,127.8

To allow for independent testing, the sum of the deviations, absolute deviations, and deviations squared were computed for independent samples of 1,000 loblolly pine and 500 white oak trees (tables 6 and 7). There was no clearcut winner or loser. For each species, the log-log model (5) looked good. The weighted regression model (3) was best for loblolly pine but average for white oak. The simple linear model looked good for white oak but poor for loblolly pine. In contrast, the robust regressions were quite poor on the white oak but better on the loblolly pine trees.

When one looks at the medium and large trees (there are not enough small trees to draw conclusions from), the robust regressions generally look good, and the weighted and log-log models look poor. For the large trees the log-log model is excellent for the white oak but average for the loblolly data set. The weighted regression model (3) is average for the white oak but very good for the loblolly pine. The simple linear model is quite poor for the loblolly but fairly good for the white oak data.

The most striking result is that no model is best or worst consistently for these data sets, even for the independent data sets. Although sample sizes are large, all models are good enough that prediction errors (random or otherwise) hide potential true differences in model performance.

The three weighted regression models (2), (3), and (4) mimic the truth best in describing the original data from which the models were developed. Trees can have cubic-foot

Table 6. — Comparison of volume table equations for 1,000-tree loblolly test data set, by size class (inches) and sample size (number)

Model	D_e	$\lvert D_e \rvert$	D_e^2
	All Diameters (1,000)		
(1)	-146	2,082	13,785
(2)	-142	2,084	13,693
(3)	15	2,090	13,596
(4)	241	2,102	13,699
(5)	58	2,088	13,631
(6)	-78	2,080	13,722
(7)	-64	2,080	13,719
	1 < D < 5 (32)		
(1)	3.66	6.54	1.66
(2)	0.03	4.46	1.22
(3)	-1.94	3.92	1.28
(4)	-1.88	3.87	1.23
(5)	-1.03	3.93	1.17
(6)	4.05	6.75	1.74
(7)	4.43	6.99	1.84
	5 ≤ D < 9 (393)		
(1)	-19.67	237.00	266.71
(2)	-53.31	241.40	273.52
(3)	-57.19	243.62	276.18
(4)	-35.69	241.37	273.37
(5)	-39.23	240.62	272.09
(6)	-9.67	236.52	266.21
(7)	-4.83	236.30	266.03
	D ≥ 9 (575)		
(1)	-130.12	1,838.78	13,516.6
(2)	-88.73	1,837.73	13,418.4
(3)	74.61	1,842.19	13,318.9
(4)	278.15	1,856.81	13,424.7
(5)	98.11	1,843.57	13,357.4
(6)	-71.96	1,837.00	13,453.8
(7)	-63.70	1,836.93	13,450.8

volume when D^2H is still 0. Model (5) does not allow for that. This model transforms both the variable of interest and the covariate. Besides causing a slight problem in estimation, this model is unnecessarily difficult to comprehend. Model (1) is clearly incorrect since it does not allow for the increase in variability in volume which is known to exist as D^2H increases (fig. 3). Models (6) and (7) allow for outliers, which did not seem to be a problem with these data.

Table 7. — Comparison of volume table equations for 500-tree white oak test data set, by size class (inches) and sample size (number)

Model	D_e	$\|D_e\|$	D_e^2
	All Diameters (500)		
(1)	-147.85	1,411.79	18,928.3
(2)	-148.09	1,412.86	18,973.3
(3)	-152.58	1,413.28	18,986.2
(4)	-154.91	1,413.44	18,991.6
(5)	2.40	1,415.74	18,534.8
(6)	-251.04	1,426.83	19,381.2
(7)	-269.26	1,430.33	19,476.6
	$1 < D < 5$ (19)		
(1)	0.570	2.007	0.811
(2)	1.555	1.766	0.914
(3)	1.599	1.780	0.920
(4)	1.594	1.777	0.919
(5)	1.572	1.598	0.775
(6)	3.229	3.229	1.297
(7)	3.603	3.603	1.425
	$5 \leq D < 11$ (260)		
(1)	6.884	241.54	453.22
(2)	15.830	241.65	453.24
(3)	15.459	241.62	453.04
(4)	15.003	241.59	452.93
(5)	-13.532	242.17	455.79
(6)	13.271	241.52	449.80
(7)	13.532	241.60	449.44
	$D \geq 11$ (221)		
(1)	-155.31	1,168.25	18,474.3
(2)	-165.47	1,169.44	18,519.1
(3)	-169.64	1,169.88	18,532.3
(4)	-171.51	1,170.07	18,537.8
(5)	14.36	1,171.97	18,078.2
(6)	-267.54	1,182.09	18,930.1
(7)	-286.39	1,185.13	19,025.8

Based on this discussion, model (3) should probably be preferred because it appears to describe the true situation in the most realistic way. It is likely though that any one of the weighted regression models with k values between 1 and 2 will be satisfactory.

To test the assumption of normality required in weighted regression, we computed skewness and kurtosis coefficients and fit distributions to tree volumes for specific D^2H classes. The class limits were selected to keep the class interval constant as much as possible and to ensure a minimum of 40 observations in each class. By setting the range of D^2H at 1,000 for loblolly and 1,500 for white oak, only the size of the last seven classes for loblolly and the last six for white oak needed to be increased to ensure at least 40 sample units in each class.

The results in tables 8 and 9 show that the volume distributions in each class are generally fairly symmetric (skewness $\sqrt{b_1}$ is close to 0). Not surprisingly, the last class for each data set, which by necessity covers a large range, is a glaring exception. Generally, the first few classes for each data set also tend to show more skewness. Trees less than 5 inches in d.b.h. have only recently been added to the data sets and are still seriously underrepresented. Positive skew occurs more frequently than negative skew, especially for the larger loblolly pine data set. In regards to kurtosis, many values are not close to the $b_2 = 3$ for the normal distribution, but tend to lie between 2 and 4 generally, most being between 2.5 and 3.5.

A χ^2 analysis indicates that the assumption of normality is only unreasonable in the first two classes and the last class for loblolly and the first and last ones for white oak. These poor fits are probably caused by inadequate representation for the first few classes and the large range of the data for the last classes.

In summary then, it appears that weighted regression models (2), (3), and (4) (with $k = 1.0$, 1.5, or 2.0) are reasonable approximate descriptions for the V-D^2H model. In addition, the assumption of a normal distribution of volume for each D^2H value does not seem unreasonable. Hence, we can validly use weighted regression estimation with confidence limits based on the assumption of normality.

Practical Implications

Data from two species representing extremes in tree form showed that a weighted regression with the same weight factor $k = 1.5$ is reasonable for both species. It is likely then that weighted regressions with this same $k = 1.5$ value can be used with confidence for most tree species. Although this model was not a clearcut winner in the statistical comparisons made with other models, it was the only model that satisfied all conditions known about the V-D^2H relationship.

Note that the use of the correct model is critical in constructing confidence limits around the estimates. For example, if the weighted regression model (with $k = 1.5$) based on all 5,134 observations is used to generate the "true" means, then table 10 shows the number of 95 percent confidence intervals containing the true mean for each of the first five models for computer simulation runs of 1,000 samples of sizes 10, 50, 100, and 500 from the loblolly pine population at six values of D^2H. Model (5) confidence limits were computed on the transformed scale and then translated back to the untransformed scale by using the usual bias correction (Mostafa and Mahmoud 1964).

Table 8. — Distribution of tree volume for D^2H classes for loblolly pine

D^2H class[a] (in^2 x ft)	n	$\sqrt{b_1}$	b_2	$\bar{v}$	S_V^2	χ^2(N)
0-1,000	272	-0.21	1.94	1.30	0.58	141.8 (10)
1,000-2,000	740	0.43	2.80	3.28	0.68	52.7 (21)
2,000-3,000	562	0.34	3.08	5.47	0.90	34.0 (19)
3,000-4,000	402	0.30	3.29	7.89	1.57	22.1 (25)
4,000-5,000	327	0.25	2.60	10.17	1.97	12.3 (14)
5,000-6,000	269	0.07	3.07	12.52	2.76	3.7 (9)
6,000-7,000	257	0.30	3.31	14.92	3.97	4.8 (11)
7,000-8,000	234	0.25	3.48	17.58	4.18	5.8 (13)
8,000-9,000	194	0.16	2.84	19.43	5.61	1.7 (9)
9,000-10,000	191	0.24	2.54	22.19	8.36	3.5 (11)
10,000-11,000	133	0.06	2.75	24.75	8.47	5.5 (12)
11,000-12,000	165	0.03	2.78	26.56	10.16	1.7 (12)
12,000-13,000	151	-0.42	3.37	28.67	13.87	5.3 (13)
13,000-14,000	122	-0.12	3.21	31.35	11.76	10.6 (14)
14,000-15,000	115	-0.12	2.92	33.72	17.79	5.1 (15)
15,000-16,000	95	0.05	2.42	36.00	18.44	4.8 (16)
16,000-17,000	98	0.23	2.68	38.97	21.31	3.8 (17)
17,000-18,000	103	0.14	3.16	40.63	19.89	8.3 (18)
18,000-19,000	77	0.35	4.02	43.00	16.94	20.2 (19)
19,000-20,000	62	-0.05	2.44	45.45	33.53	3.6 (19)
20,000-21,000	52	0.22	2.78	49.37	32.11	4.5 (21)
21,000-22,000	51	0.18	3.33	50.55	36.92	9.5 (23)
22,000-23,000	49	0.47	3.99	52.84	30.79	8.6 (18)
23,000-24,000	58	0.02	2.59	54.19	28.34	1.6 (17)
24,000-25,500	62	0.33	2.74	58.87	43.98	4.1 (20)
25,500-27,500	60	0.09	2.96	62.38	57.63	9.1 (21)
27,500-30,000	53	-0.27	2.58	68.51	69.56	11.0 (21)
30,000-32,500	49	-0.23	3.56	70.46	94.05	16.1 (23)
32,500-36,500	47	-0.13	3.44	79.71	70.22	14.3 (25)
36,500-42,800	48	0.12	2.62	91.26	144.20	9.1 (25)
42,800-175,000	52	2.86	10.93	130.78	3,180.98	1,761.2 (37)

[a]Class sizes were selected for consistency and to ensure an adequate sample size in each class. The larger value size classes were increased to ensure a minimum of 40 observations per class.

It is immediately obvious that models (1), (2), (4), and (5) give quite misleading results, particularly for the more important large D^2H values. Model (3), on the other hand, gives generally dependable results for all sample sizes at all D^2H values.

The weighted regression model with k = 1.5 should be used for loblolly pine and white oak, and probably most other tree species, in preference to the other models considered for volume table construction. Computing the coefficients for this model is simple. It requires only a multiple regression package to fit

$$V/(D^2H)^{0.75} = \alpha/(D^2H)^{0.75} + \beta \quad (D^2H)^{0.25}$$

— see Cunia (1964) for more detail. Such packages are widely available for both computers and programable calculators.

Table 9. — Distribution of tree volume for D^2H classes for white oak

D^2H class[a] (in^2 x ft)	n	$\sqrt{b_1}$	b_2	$\bar{v}$	S_V^2	χ^2(N)
0-1,500	166	-0.62	2.25	2.24	1.37	145.1 (16)
1,500-3,000	252	0.53	2.70	5.17	1.56	52.0 (32)
3,000-4,500	187	0.26	3.07	8.85	2.83	32.0 (30)
4,500-6,000	119	-0.20	3.19	12.68	3.72	33.0 (35)
6,000-7,500	102	0.07	5.61	15.85	6.33	108.8 (26)
7,500-9,000	89	-0.09	2.74	19.69	8.66	5.7 (13)
9,000-10,500	67	-1.08	5.37	21.81	13.04	252.8 (14)
10,500-12,000	88	0.19	4.11	26.92	12.89	17.7 (20)
12,000-13,500	55	-0.18	3.07	30.14	24.35	5.7 (15)
13,500-16,000	69	0.03	2.85	35.34	23.62	3.4 (16)
16,000-19,000	66	-0.19	2.91	42.74	27.35	4.6 (19)
19,000-23,000	61	0.11	2.24	50.01	58.01	5.2 (23)
23,000-28,000	52	-0.76	4.21	58.65	143.12	52.8 (28)
28,000-36,000	52	-0.64	3.40	74.95	275.06	37.4 (36)
36,000-83,000	59	0.18	2.61	124.12	1,199.71	15.9 (20)

[a]Class sizes were selected for consistency and to ensure an adequate sample size in each class. The larger value size classes were increased to ensure a minimum of 40 observations per class.

Table 10. — Number of 95 percent confidence intervals out of 1,000 that covered the true mean V value at a specified D^2H_0 (in² x ft), by sample size (number)

D^2H_0	Model (1)	(2)	(3)	(4)	(5)	Model (1)	(2)	(3)	(4)	(5)
	n = 10					*n = 50*				
3,055.91	990	968	948	925	889	956	968	938	900	785
6,111.82	943	912	936	948	944	988	879	928	937	890
$\bar{D^2H}$ 9,167.72	839	865	924	949	948	891	813	919	929	939
64,151.76	658	836	907	937	929	549	770	893	906	881
119,135.80	671	837	906	937	912	557	771	893	905	864
174,120.00	674	838	905	937	912	564	769	893	905	863
	n = 100					*n = 500*				
3,055.91	931	970	933	863	713	805	982	950	646	296
6,111.82	991	876	932	893	825	965	813	939	617	328
$\bar{D^2H}$ 9,167.72	923	812	923	889	901	893	719	941	605	552
64,151.76	541	755	914	881	876	408	616	942	584	866
119,135.80	548	757	911	880	869	413	611	942	581	858
174,120.00	551	758	909	879	856	418	608	942	580	858

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Among seven volume table equations compared on large loblolly pine *(Pinus taeda* L.) and white oak *(Quercus alba* L.) data sets, no model was convincingly best. The variance assumption of the simple linear regression model (volume vs. diameter squared times height) was clearly violated. The weighted regression model with k = 1.5 seemed to approximate the truth best. The assumption of a normal distribution for volume at each value of D^2H seemed reasonable as tested by χ^2. Confidence limits for this model, based on various sample sizes, were much more dependable than for the other models, assuming that the true model is the weighted regression with k = 1.5 for the entire data set.

KEYWORDS: *Pinus taeda, Quercus alba,* likelihood, confidence limits, weighted regression, robust regression.

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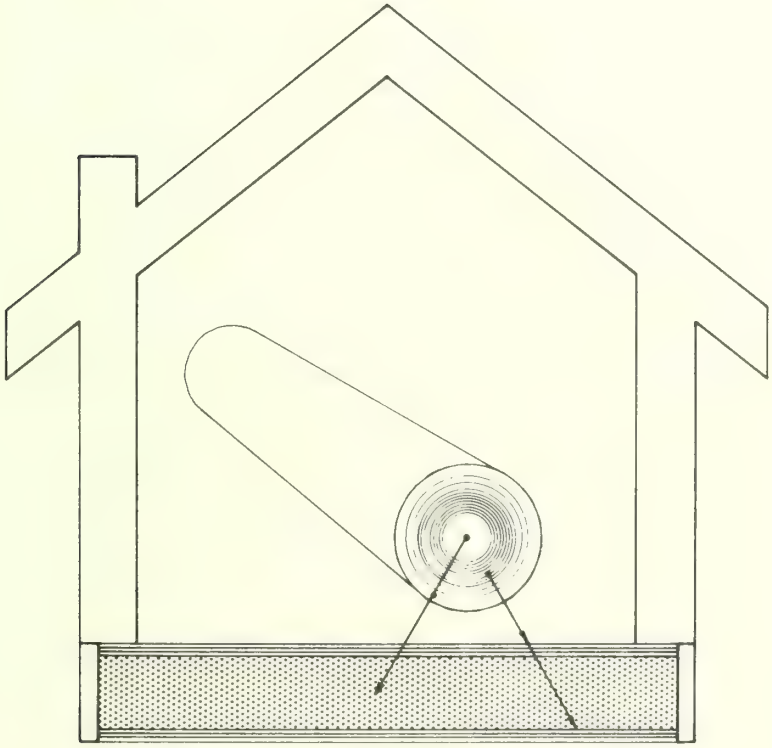
Economic Feasibility of Manufacturing COM-PLY® Floor Joists

Gerald A. Koenigshof



COM-PLY® Report 26

COM-PLY® is a registered trademark of the American Plywood Association.

November 1983
Southeastern Forest Experiment Station
200 Weaver Blvd.
Asheville, North Carolina 28804

Economic Feasibility of Manufacturing

COM-PLY® Floor Joists

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Cooperative Research by
U.S. Department of Agriculture, Forest Service
Southeastern Forest Experiment Station
and
U.S. Department of Housing and Urban Development
Division of Energy, Building Technology
and Standards

Preface

This report is one of a series on the possibilities of producing house framing and structural panels with particleboard cores and veneer facings. These COM-PLY or composite materials were designed to be used interchangeably with conventional lumber and plywood in housing. Research on structural framing was initially limited to COM-PLY studs but has now been extended to include larger members such as floor joists and roof truss framing.

In 1973, the home-building industry faced a shortage of lumber and plywood and consequent rising prices. Both industry and government recognized that this was not a temporary problem and that long-range plans for better using the Nation's available forest resources would be necessary.

The Forest Service of the U.S. Department of Agriculture and the U.S. Department of Housing and Urban Development accelerated cooperative research on ways to utilize the whole tree. They concentrated on composite wood products made with flakeboard and veneer as a way of using not only more of the tree stem, but also using less desirable trees and a greater variety of tree species than would be used for conventional wood products. The flakeboard which constitutes a large portion of COM-PLY studs and joists is made from flaked-up wood that comes from forest residues, mill residues, or low-quality timber. Thus, such composites could greatly increase the amount of lumber and plywood available for residential construction, our major use of wood, without eroding the Nation's timber supply.

Research on composite wall and floor framing was performed by the Wood Products Research Unit, Southeastern Forest Experiment Station, Athens, Georgia. The American Plywood Association cooperated in these studies by designing and testing composite panel products that are interchangeable with plywood. Both types of products have been incorporated in demonstration houses.

Included in this series will be reports on structural properties, durability, dimensional stability, strength, and stiffness of composite studs and joists. Other reports will describe the overall project, compare the strength of composite and solid wood lumber, suggest performance standards for composite lumber, and provide construction details on houses incorporating such lumber. Still others will explore the economic feasibility of manufacturing composite lumber and panels and estimate the amount and quality of veneer available from southern pines. These reports, called the COM-PLY series, will be available from the Southeastern Forest Experiment Station and the U.S. Department of Housing and Urban Development.

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ABSTRACT

Investments, production costs, and probable returns for manufacture of COM-PLY floor joists are presented. The report shows that it is possible to obtain a 25 percent or greater after-tax internal rate of return on the investment.

Keywords: Manufacturing costs, lumber cost, economics of lumber manufacture, cost analysis, floor framing costs.

Figure 1.--COM-PLY joist used for framing floors of houses.

Cooperative research by the Forest Service, U.S. Department of Agriculture, and the U.S. Department of Housing and Urban Development has led to development of a new composite lumber product. The new product, called COM-PLY, has potential for significantly increasing our supply of framing for building houses. Made with a structural sandwich construction of 1.5-in-thick flakeboard core placed between 0.25-in-thick layers of solid wood veneers (fig. 1), COM-PLY floor joists are intended to be direct substitutes for sawed lumber now widely used for floor framing (fig. 2).

COM-PLY joists need to be priced competitively with sawed lumber so builders will have incentive to purchase them. Floor joist sizes considered for manufacture in this study are nominal 2 x 8's and 2 x 10's. The only lengths considered are 12 ft for 2 x 8's and 14 ft for 2 x 10's since these sizes are the most commonly used by builders; however, COM-PLY joists can be manufactured in virtually any size that is practical to handle and ship to the job site.

Potential manufacturers want to know how much it will cost to manufacture

Figure 2.--COM-PLY joists being installed in the floor of a house in Marietta, Georgia.

COM-PLY joists. They also want to know if a COM-PLY lumber factory would be a profitable investment--one that would have a greater rate of return on the investment than a sawmill. This report presents estimates on the amount of investment required to build a flakeboard, veneer, and joist-laminating factory; the annual sales and cost of manufacturing COM-PLY joists and the operating cash flow; and the annual net cash flow and internal rate of return.

Any financial feasibility study is only as good as the assumptions upon which it is based. In this study, we assumed that the factory would be located in the South and would use southern pine and hardwoods. Cost assumptions are based on representative industry averages and therefore do not reflect values for any specific company. Much detail has been included in this report to provide guidelines for readers who want to make their own analysis.

Results presented in the report do not guarantee that any firm can profitably manufacture COM-PLY joists--profitability depends on competent managerial skills, market demand, production efficiency, and other business factors. The results strongly indicate that it is economically feasible to manufacture COM-PLY joists. Although a specific firm's price, cost assumptions, and quantity may vary from those assumed in this report, minor variances would not affect the overall conclusions reported. Companies contemplating the manufacture of COM-PLY joists should substitute their own local cost estimates in a similar analysis to check economic feasibility for their particular location.

Financial Feasibility Analysis

Process Used for Manufacture

COM-PLY joists are 1-1/2 x 7-1/4 or 1-1/2 x 9-1/4 in. in cross section and serve as substitutes for 2 x 8 or 2 x 10 sawed joists in framing floors of houses. Unpublished research by Koenigshof and J. E. Duff (Athens, Ga.) showed that by using flakes in the coreboard oriented lengthwise of the COM-PLY joist greatly increased joist strength, stiffness, and fire resistance. Approximately 65 percent of the wood particles in the core should be oriented flakes. The remaining 35 percent of the particles can have a geometry like that used in conventional particleboard underlayments (typically, ring-flaked planer shavings). The flakes are made by flaking veneer peeler cores or other roundwood in a drum-type flaker. The flaker knives are set to cut ribbons of wood 1-1/4 to 3-1/4 in. wide and 0.02 to 0.03 in. thick. The ribbons of wood are broken into flakes of an average width of 0.25 ± 0.125 in. during the flaking process. The result will be a flake that on the average will be 1/4 in. wide, 2-1/4 in. long, and 1/40 in. thick. Ribbons of wood from the flaker can be passed through a hammermill with a large-size screen to break the ribbon into flakes 1/4 in. wide. Wider flakes cannot be used because they tend to curl and will not be uniformly coated with resin during blending. However, length is not critical as long as the length-to-width ratio results in effective orientation.

These specifications are typical for mechanically oriented flakeboard cores. However, research by T. M. Maloney at Washington State University, Pullman, Wash., and by Thomas E. Peters with Morrison-Knudsen, Inc., Boise, Idaho, shows that flakeboards made with ring-flaked particles and Douglas-fir planer shavings have strength and stiffness properties approaching flakeboard with drum-cut flakes when the particles are electrically oriented. Therefore, quite a wide variety of flakes can be used in COM-PLY joists provided that the proper orientation equipment is used to achieve effective particle alignment.

Fine particles that are considered dust or flour and pass through a 30- to 40-mesh screen should be removed as completely as possible from the wood supply. Fine particles retained on a 20- to 40-mesh screen, preferably a 12 to 14 mesh, can make up 15 to 20 percent of the wood in the particleboard. Bark particles can constitute up to 5 percent for fiberous barks such as yellow-poplar. Moisture content of the wood particles before blending should not exceed 6 percent of the ovendry weight of the wood.

To keep the weight of the joist reasonably low, the species of wood can be 50 to 100 percent medium-to-dense softwoods such as southern pine or Douglas-fir; 35 to 50 percent low-to-medium dense hardwoods such as yellow-poplar, sweetgum, or sycamore; and, not more than 15 percent dense hardwoods such as oak, hickory, or beech. Any combination of species can be used provided that the joist will pass the Performance Standards[1] for COM-PLY floor joist. COM-PLY joist made with veneers of oak, sweetgum, yellow-poplar, southern pine, and combinations of these woods have been fabricated and tested for strength and stiffness performance and the results were satisfactory for use. The weighted average dry density of the wood supply used in this study was 28.82 lb/ft^3 and the specific gravity was 0.462.

The flakeboard core can have a specific gravity of 0.6 $\pm$ 5 percent or density of 37.44 $\pm$ 5 percent lb/ft^3. The board can be homogenous or three layered. If homogenous, the resin content will be 6 percent phenolic solids based on the ovendry weight of the wood and the wax content, 0.5 percent solids. If three layered, the resin content will be 6.5 percent phenolic solids in the face layers and 5.5 percent in the inner layer; the wax content, 0.6 percent solids in the face layers and 0.4 percent in the inner layer. For three-layered board, most of the wood fines can be in the face layers, constituting 50 percent of the board thickness. The three-layered board is preferable to the homogenous board.

The internal bond of the board should be more than 100 lb/in^2. Thickness swelling cannot exceed 8 percent after a 24-hour water soak; wax content can be increased to decrease thickness swelling. Phenolic resin must be catalyzed to cure in 10 to 11 minutes when the platen temperature is 400° F for boards 1-1/2 in. thick. Resin in the face layers need not be catalyzed.

The flakeboard core is made on a standard multiplaten hot-press typically used to make commercial particleboard. The processes of manufacturing particleboard are well known and will not be repeated here. However, the press line must accommodate the thick mat required for 1-1/2-in-thick board. The daylight opening of the press must be large enough for the thick board; a prepress to reduce mat thickness is also essential.

To produce oriented flakes in the core, the forming machine should have mechanical- or electrical-flake orientating capability. The flakes should be oriented with their lengthwise dimension parallel to the lengthwise dimension of the flakeboard. The mat can be pressed to a board thickness of 1-1/2 in. by using stops or other means of controlling thickness on the particleboard press. The board surfaces should not be sanded after manufacture.

Veneer, 1-1/4 in. thick, is rotary-cut from southern pine, yellow-poplar, oak, and mixed hardwood peeler blocks and dried to an average of 3 percent moisture content. Other thicknesses of veneer or another species mix can be used by manufacturers if they find them more practical for their particular use. There was no unreasonable amount of spin-out, splitout, or other veneer peeling difficulties experienced in production facilities that supplied 1/4-in-thick southern pine, yellow-poplar, sweetgum, and oak veneer to the Athens laboratory for technical research projects. Dense hardwood such as oak or hickory is assumed to constitute not more than 15 percent of the veneer volume. The choice of 15 percent was arbitrary, and the intent was to keep the weight of the product reasonably low but to still use some of the higher density woods that are in relatively abundant supply.

For this study, the veneer was clipped into sheets 2 to 2-1/2 ft wide by 8 ft long, then glued into panels on a standard plywood hot-press or on a particleboard press. For making 2 x 10 joists, the panels are five veneers

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[1] Duff, John E.; Koenigshof, Gerald A.; Wittenberg, Dick C. Performance standards for COM-PLY floor joists. Res. Pap. SE-192. COM-PLY Rep. 14. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station and Washington, DC: U.S. Department of Housing and Urban Development; 1978. 17 p.

thick; for 2 x 8 joists, four veneers thick. The panels are then scarfed or finger-jointed on each end and glued together to form a continuous ribbon of parallel-laminated veneer (PLV) lumber, which is crosscut into panel lengths equal to the length of lumber being made.

The veneers in PLV lumber are glued together with a phenolic adhesive identical to that used for making plywood. Adhesive is applied at a spread rate of 50 lb/M ft^2 of glueline. The glued panels are ripped into pieces 1-1/2 in. wide, called cords. The cords are beveled on two corners during ripping by a V-shaped cutterhead to provide eased-edge lumber. For this study, these cords were then glued to the edge of a flakeboard core in a lumber edge bonding machine with radio-frequency (RF) heating to form a piece of COM-PLY lumber. The cords cut from the PLV lumber are glued to the particleboard cores with phenol-resorcinol adhesive at a spread rate of 90 lb/M ft^2 of glueline. Glue should be spread on both mat surfaces to obtain the maximum quality bond.

General Requirements

This economic analysis assumes that construction of two COM-PLY factories was begun in 1979 at prevailing prices. Two factory sizes are considered: Case I is a factory that produces 169,712,000 board feet (fbm) per year and Case II, 91,282,000 fbm per year. For both cases it is assumed that 45 percent of production is 2 x 8-12 joists and 55 percent is 2 x 10-14 joists. The factories are assumed to operate 250 days per year, three shifts per day at an efficiency of 85 percent. Approximately 108 days would be for 2 x 8 production and 142 days for 2 x 10 production.

Investment

Land. The site selected for this analysis is located in the south-central United States and consists of 50 acres for Case I and 30 acres for Case II. Raw land is assumed to cost $6,000 per acre. The developed site, including amenities such as grading, drainage, settling pond, paving, fencing, rail spur, water supply, fire protection, sanitary facilities, and outside lighting, would cost $987,000 for Case I and $593,000 for Case II:

Item	Cost	
	Case I	Case II
Land @ $6,000/acre	$300,000	$180,000
Skimming and grading	60,000	36,000
Drainage and culverts	30,000	18,000
Settling pond	20,000	12,000
Rockfill (@ $5/$yd^3$)	57,000	35,000
Asphalt paving (@ $.60/ft²)	48,000	29,000
Crushed rock (@ $7/$yd^3$)	21,000	12,600
Fencing (@ $10/ft)	59,000	35,400
RR spur track (@ $30/ft)	24,000	14,000
12-in. water service	36,000	22,000
12-in. underground sprinkler loop, hydrants, and hose stations	200,000	120,000
Domestic water service	2,000	1,000
Sanitary system	40,000	24,000
Effluent treatment	40,000	24,000
Outside lighting	50,000	30,000
Total	$987,000	$593,000

Buildings. The amount of building space required is:

Type of building	Square footage	
	Case I	Case II
Boilerhouse	4,800	2,880
Refining and drying	18,000	10,800
Flakeboard production	36,000	21,600
PLV green end	6,400	3,840
Veneer and PLV production	160,000	96,000
Laminating and finished warehouse	84,000	50,400
Chipper building	4,000	2,400
Electrical and hydraulic rooms	4,000	2,400
In-plant shops, lunchrooms, and offices	8,000	4,800
Total	325,200	195,120

Costs for all buildings (manufacturing plus office space) including slabs, footings, lighting, heating, sprinklers, and wall finishing are $4,260,000 for Case I and $2,649,800 for Case II:

Item	Unit cost/ft^2	Total cost	
		Case I	Case II
Prefab steel buildings (insulated and erected)	$7.00	$2,276,400	$1,365,840
Slabs and footings	3.00	975,600	585,360
Lighting	.80	260,160	156,000
Heating	.70	227,640	136,600
Inside sprinklers	.80	260,160	156,000
Office and labs (partitions and finishing)	--	60,000	50,000
General office (6,000 ft^2 outside of plant)	--	200,000	200,000
Total		$4,260,000	$2,649,800

Machinery and machinery foundations. Table 1 provides a detailed list of machinery, machinery installation, and machinery delivery cost. Machinery cost for Case I is $29,652,100 and for Case II, $19,658,700. The cost of machinery foundations is shown in table 2.

Cash. In this analysis, we assume that the equivalent of 2 months' payroll is sufficient cash to meet the payroll, provide petty cash, and otherwise meet cash needs to operate the business. In a later section, we show that the annual labor cost in 1979 would be $3,192,500 for Case I and $2,197,500 for Case II if the plant were operating at full capacity. Thus, cash required was assumed to be $532,083 for Case I and $366,250 for Case II.

Inventory. Investment is required for raw materials, for materials being processed, and for finished products awaiting shipment. In this study, one-twelfth of the annual cost of raw materials for a factory operating at full capacity was assumed to be sufficient to cover all requirements for inventory investment. It will be shown that the total annual cost of raw materials for Case I is $15,258,714 and $8,396,788 for Case II. Therefore, the investment required for inventory is $1,271,560 for Case I and $699,732 for Case II.

Accounts receivable. A considerable investment is required to cover sales to customers who do not pay immediately upon delivery. These accounts receivable may typically be paid in 10 to 60 days. The average collection period was assumed to be 40 days. Investment to cover accounts receivable was considered to be 40 days of sales. Sales will vary with the unit price received for products and the quantity produced each year.

In 1979 the average price for No. 2 southern pine KD 2 x 8-12's was $282 per thousand board feet (M bm) and for 2 x 10-14's, $352/M bm.[2] However, these prices were above the long-term trend prices because of strong demand for lumber in housing during 1979. The trend prices are $270/M bm for 2 x 8-12's and $317/M bm for 2 x 10-14's. Trend prices are used in economic studies to strike an average for an investment period. The use of current prices that are above the trend at the time of making an analysis would be misleading because they would be artificially high, and a higher return on investment would be shown than is actually achievable; the use of current prices that are below the trend would show a lower return on the investment than is actual, and the investment would be rejected when it would be quite feasible.

Based on trend prices, the sales for this study are:

Joist type	Annual M bm production		Price/M bm		Annual sales
		CASE I			
2 x 8-12	76,370.4	x	$270	=	$20,620,000
2 x 10-14	93,341.6	x	317	=	29,589,300
Total					$50,209,300
		CASE II			
2 x 8-12	41,076.9	x	$270	=	$11,090,750
2 x 10-14	50,205.0	x	317	=	15,915,000
Total					$27,005,750

The accounts receivable working capital for 40 days of sales is $5,502,387 for Case I and $2,959,534 for Case II.

Contingency and Engineering. A consulting engineering firm (Columbia Engineering, Eugene, Oreg.) estimated costs at $2 million for Case I and $1,500,000 for Case II. Investment contingency in the order of 10 percent of the site, building, machinery, and foundation was used by the consultants. The amount is $3,578,000 for Case I and $2,348,000 for Case II. Total engineering and contingency investment is $5,578,000 for Case I and $3,848,000 for Case II.

The investment costs and timing of investments are shown in table 3. The total investment for Case I is $48,612,500 and for Case II, $31,355,500.

[2] Evans, David S., ed. 1979 Random lengths yearbook. Eugene, OR: Random Lengths Publications, Inc.; 1979. 186 p.

Table 1.--Machinery and machinery cost for a COM-PLY joist factory

Machinery or associated item	Cost	
	Case I	Case II
	Dollars	
LOG PROCESSING EQUIPMENT		
Log storage and handling (mobile equipment)		
Log lift machines	251,000	251,000
Block lift machines	175,600	87,800
	426,600	338,800
Log debarking and bucking		
Log decks	360,000	180,000
Hydraulic loaders	108,000	54,000
Log conveyors	38,000	19,000
Crook saws	30,400	15,200
Log conveyors	31,600	15,800
Barker infeed	12,200	6,100
Barkers	242,600	121,300
Log conveyor (barker outfeed)	16,900	0
Log conveyors (to sorting decks)	58,600	29,300
Log sorting deck	75,900	0
Transfer decks	155,000	77,500
Log conveyors	34,000	17,000
Block saws	94,000	47,000
Block conveyor (at saws)	20,000	10,000
Block pockets (residual)	12,000	12,000
Residual block transfer	40,000	0
Block conveyor	12,600	0
Block conveyor with kickers	16,000	8,000
Block pockets	16,000	8,000
	1,373,800	620,200

Continued

Table 1.--Machinery and machinery cost for a COM-PLY joist factory--Continued

Machinery or associated item	Cost	
	Case I	Case II
	Dollars	
Chipping and chip handling		
Residual log conveyor	17,500	0
Residual log transfer	27,600	0
Chipper feed conveyor	23,700	23,700
84-in. whole-log chipper	35,000	35,000
Chip screen	10,500	9,000
Chipper discharge conveyor	9,000	9,000
Chip conveyor to surge bin	31,900	27,000
Chip surge bin	15,000	15,000
HP pneumatic system (chips to storage)	25,000	25,000
Overs and fines conveyor (to hog fuel)	11,000	11,000
Lily pad conveyor and saws	10,000	5,000
Lily pad conveyors (gathering)	34,400	5,000
Lily pad chipper feed conveyor	6,000	6,000
Lily pad chipper outfeed	6,800	6,800
Metal detector	5,600	5,600
Lily pad chipper	15,000	15,000
	284,000	198,100
Waste conveyors and hog		
Waste conveyor under #1 barker	40,400	0
Waste conveyor under #2 barker	25,000	25,000
Waste conveyor under #1 transfer	19,200	0
Waste conveyor under #2 transfer	19,200	19,200
Waste conveyor under #1 sawline	29,800	0
Waste conveyor under #2 sawline	26,000	26,000
Waste gathering cross conveyor	31,900	26,000
Hog feed conveyor	22,800	22,800
Hammer hog (#55)	38,700	38,700
Hog discharge conveyor	14,000	14,000
HP pneumatic system to fuel pile	30,000	25,000
Metal detector	5,600	5,600
	302,600	202,300

Continued

Table 1.--Machinery and machinery cost for a COM-PLY joist factory--Continued

Machinery or associated item	Cost	
	Case I	Case II
	Dollars	
Steaming vats	750,000	400,000
Control and electrical rooms, platforms, walkways, etc.	140,000	90,000
VENEER AND PLY EQUIPMENT		
Green-veneer production		
Log decks Lathe chargers Lathes (#277) Trash gate Veneer tray (short coupled) ->* Clipper infeed table Veneer chain Lathe and tray drives Trash return	1,040,000	520,000
Core conveyor and pockets	15,000	12,000
Clippers	66,000	33,000
Clipper controls	78,000	39,000
Automatic veneer stackers	120,000	60,000
Chipper feed conveyor	12,000	12,000
Veneer chipper	30,000	30,000
	1,361,000	706,000
Veneer drying		
Veneer dryers Dryer feeders Dryer outfeed ->* Veneer sorting tables Moisture detectors	1,500,000	750,000

Continued

Table 1.--Machinery and machinery cost for a COM-PLY joist factory--Continued

Machinery or associated item	Cost	
	Case I	Case II
	Dollars	
PLV production		
Layup line and stack conveyors	100,000	75,000
Glue kitchen	25,000	25,000
Prepress		
Press loaders		
Hot-press[a] (6 ft x 8 ft -- 20 openings) ->	950,000	525,000
Press unloaders		
	1,075,000	625,000
Panel sawing and handling, chipping waste system, etc.		
Panel saws	110,000	110,000
Panel handling	40,000	40,000
Dry waste hog	15,000	15,000
Hog feed conveyor	8,000	8,000
LP hog pneumatic system	30,000	25,000
Chipper discharge conveyor	15,000	12,000
Chip metering bin	12,000	10,000
Chip screen	6,500	6,000
HP pneumatic system to chip pile	40,000	30,000
Fines and overs to hog fuel	30,000	25,000
Veneer carts	10,000	5,000
Resin bulk storage tanks	20,000	12,000
	336,500	298,000

Continued

Table 1.--Machinery and machinery cost for a COM-PLY joist factory--Continued

Machinery or associated item	Cost	
	Case I	Case II
	Dollars	
FLAKEBOARD EQUIPMENT		
Raw material receiving and handling		
Truck dump and hopper	90,000	90,000
Dump hopper discharge conveyor	20,000	20,000
Radial stacker	60,000	60,000
Chip reclaim hopper and conveyor	35,000	30,000
HP pneumatic system	80,000	60,000
	285,000	260,000
Refining and drying		
HP pneumatic system to refiner metering bin	50,000	35,000
Electromagnet	9,000	7,000
Flaker metering bin	60,000	40,000
Chutes and switch gates	10,000	6,500
Conveyors to refiners	36,000	24,000
Vibrating refiner feeders	24,000	16,000
Ring flakers	330,000	220,000
Roundwood infeed deck	30,000	30,000
Slasher table	50,000	50,000
Apron conveyors to refiners	50,000	35,000
Waste conveyor from slasher	15,000	15,000
Drum flakers	585,000	390,000
LP pneumatic system to dryer feed bins	180,000	120,000
Distributing conveyors to dryer feed bins	20,000	12,600
Flake dryer feed bins	90,000	60,000
Rotary drum dryers ("Heil" 125SD42)	498,500	300,000
Wood-fired dryer furnace	345,000	207,000
Dry fuel silo	80,000	50,000
Fuel refiner	8,000	6,000
Conveyor to fuel refiner	3,000	2,000
Fuel screen	5,000	3,000
Fuel metering bin	30,000	25,000
Conveyor to fuel metering bin	5,000	4,000
HP air system to burners	40,000	30,000
Dryer pneumatic system	306,500	185,000
Walkways, platforms, and support steel	75,000	40,000
	2,935,000	1,913,100

Continued

Table 1.--Machinery and machinery cost for a COM-PLY joist factory--Continued

Machinery or associated item	Cost	
	Case I	Case II
	Dollars	
Material classification and blending		
Fire dump conveyors	30,000	20,000
Classifying screens	84,600	45,000
Overs conveyor to hammermill	12,000	8,000
Hammermill	12,000	8,000
Conveyor to accepts conveyor	15,000	12,000
Fines gathering conveyor	8,000	6,000
HP air system (fines to fuel silo)	30,000	20,000
Flake conveyor to dry storage bin	97,000	80,000
Dry flake storage bin	95,000	90,000
Conveyors to blender metering bins	70,000	50,000
Blender metering bins	200,000	150,000
Electromagnets	18,000	12,000
Weigh belts	36,000	22,000
Weigh scales and instrumentation	35,000	35,000
Blenders	90,000	70,000
Resin and wax mixing system, instrumentation, pumps, and piping	80,000	60,000
Resin and wax bulk storage tanks	40,000	25,000
Conveyors-blenders to forming	40,000	40,000
Distribution conveyors over forming	26,000	26,000
Platforms, walkways, and structural steel	30,000	25,000
	1,048,600	804,000

Continued

Table 1.--Machinery and machinery cost for a COM-PLY joist factory--Continued

Machinery or associated item	Cost	
	Case I	Case II
	Dollars	
Flakeboard production line		
Forming machine and conveyor	500,000	400,000
Press[b]	2,525,000	1,950,000
Loader and unloader	340,000	240,000
Caul system, weight scales, board separator, and electrics	750,000	500,000
Cleanup screw	30,000	20,000
Mat saw pneumatics	20,000	15,000
Reject hopper with outfeed	40,000	25,000
Reject conveyor to bin	60,000	40,000
Reject bin with outfeed	20,000	20,000
Press exhaust hood and fans	15,000	12,000
Press pit cleanup system	6,000	5,000
Bypass stacker, feeder, skin and trim saws (including transfers and trim breakers)	230,000	180,000
Stacker and outfeed rolls	45,000	30,000
Trim conveyors	25,000	15,000
Trim hog	15,000	12,000
Hog trim blower (to fuel)	35,000	30,000
Saw pneumatic system	35,000	25,000
Support steel, walkways, etc.	40,000	25,000
Press stops	15,000	10,000
Aluminum cauls	150,000	80,000
Saw blades	10,000	6,000
Miscellaneous chutes and hoppers	30,000	20,000
	4,936,000	3,660,000

Continued

Table 1.--Machinery and machinery cost for a COM-PLY joist factory--Continued

Machinery or associated item	Cost	
	Case I	Case II
	Dollars	
FINGER JOINTING AND LAMINATING		
Finger jointing, gluing machinery, and tooling	488,300	244,200
PLV ripsaw	78,000	78,000
Flakeboard ripsaw	80,000	80,000
Panel feeders	80,000	60,000
Residual flakeboard gluer	92,000	92,000
Joist laminators	1,241,200	827,500
Engineering and research and development	72,000	72,000
Arbors and tooling (PLV)	26,000	26,000
Arbors and tooling (flakeboard)	29,000	29,000
Material handling conveyors	112,000	75,000
Offbearing and stacking	incl. above	incl. above
Waste conveyors	12,000	12,000
Waste hog	6,000	6,000
LP waste pneumatic system	80,000	75,000
HP pneumatic relay system	40,000	25,000
Glue kitchen	10,000	10,000
Resin storage tanks	20,000	15,000
	2,466,500	1,726,700
MISCELLANEOUS EQUIPMENT		
Boiler and fuel handling equipment		
Fuel stacking and reclaiming	100,000	100,000
Fuel conveyor system	150,000	150,000
250 lb/in^2 boiler (70,000 lb; 50,000 lb)	924,000	650,000
Air systems	200,000	130,000
Control	80,000	60,000
Pumps and piping	115,000	75,000
	1,569,000	1,165,000

Continued

Table 1.--Machinery and machinery cost for a COM-PLY joist factory--Continued

Machinery or associated item	Cost	
	Case I	Case II
	Dollars	
Auxiliary equipment		
Air compressors	90,000	50,000
Air receivers	20,000	10,000
Air dryers (instruments)	12,000	8,000
Forklifts and loaders	280,000	150,000
Propane tanks	Lease	Lease
Air-conditioning	50,000	30,000
Plumbing fixtures	10,000	8,000
Cooling tower	60,000	40,000
Condensate pumps and tanks	150,000	90,000
Truck scales	16,000	16,000
Knife-grinding and saw-filing equipment	50,000	35,000
Machine shop	30,000	25,000
Lab equipment	30,000	30,000
Maintenance equipment and small tools	100,000	80,000
Spare parts	100,000	60,000
Yard truck and sweeper	34,000	34,000
	1,032,000	666,000
Electrical equipment		
Log processing	136,000	82,000
Block conditioning	25,000	20,000
Veneer, PLV manufacturing	299,000	185,000
Chip and hog fuel receiving and storage	20,000	20,000
Refining and drying	293,000	180,000
Classification and blending	75,000	60,000
Flakeboard production	183,000	110,000
Finger jointing and laminating	99,000	65,000
Boiler and fuel handling	110,000	60,000
	1,240,000	782,000

Continued

Table 1.--Machinery and machinery cost for a COM-PLY joist factory--Continued

Machinery or associated item	Cost	
	Case I	Case II
	Dollars	
Piping equipment		
Owner-supplied major valves, pumps, and instrumentation	150,000	100,000
Pollution abatement		
Log debarking and bucking	12,000	8,000
Block conditioning	30,000	20,000
Veneer and PLV production	100,000	50,000
Chip and hog fuel receiving and storage	10,000	10,000
Refining and drying	150,000	100,000
Classification and blending	32,000	24,000
Flakeboard production	43,000	35,000
Finger jointing and laminating	40,000	25,000
Boiler and fuel handling	100,000	75,000
	517,000	347,000
EQUIPMENT INSTALLATION		
Mechanical		
Barking and bucking center	340,000	190,000
Block conditioning (incl. w/equipment)	0	0
Veneer and PLV manufacturing	427,000	230,000
Chip and hog fuel receiving and storage	28,500	28,500
Refining and drying	290,000	175,000
Classification and blending	108,000	100,000
Flakeboard production line	529,000	400,000
Finger jointing and laminating	364,000	220,000
Boiler and fuel handling	157,000	140,000
	2,243,500	1,483,500

Continued

Table 1.--Machinery and machinery cost for a COM-PLY joist factory--Continued

Machinery or associated item	Cost	
	Case I	Case II
	Dollars	
Piping		
Barking and bucking center	78,000	40,000
Block conditioning	50,000	30,000
Veneer and PLV manufacturing	171,000	103,000
Chip and hog fuel receiving and storage	12,000	12,000
Refining and drying	234,000	140,000
Classification and blending	70,000	60,000
Flakeboard production line	183,000	130,000
Finger jointing and laminating	50,000	30,000
Boiler	656,000	500,000
	1,504,000	1,045,000
Electrical		
Barking and bucking center	194,000	116,000
Block conditioning	53,000	35,000
Veneer and PLV manufacturing	427,000	256,000
Chip and hog fuel receiving and storage	34,000	34,000
Refining and drying	293,000	176,000
Classification and blending	100,000	80,000
Flakeboard production line	322,000	225,000
Finger jointing and laminating	172,000	120,000
Boiler and fuel handling	157,000	140,000
	1,752,000	1,182,000
Freight	424,000	296,000
Total	29,652,100	19,658,700

[a]Case I--2 presses; Case II--1 press.

[b]Flakeboard press for: Case I, normal 5-1/2 ft x 24-1/2 ft--20 openings; Case II, normal 5-1/2 ft x 16-1/2 ft--16 openings.

Table 2.--Type of machinery foundation and foundation costs for Case I and Case II

Foundation item	Cost	
	Case I	Case II
	Dollars	
Log infeed decks	32,500	17,000
Log conveyors, debarker, and cutoff saws	60,000	30,000
Transfer decks	30,000	15,000
Block pockets and aprons	18,000	9,000
Block conditioning (incl. w/equipment)	0	0
Lathe infeed deck and apron	12,000	6,000
Charger, lathe, core transfer and pockets	45,000	25,000
Veneer chipper and feed conveyor foundation, pit and trench	13,500	11,000
Clipper and tray area	20,000	10,000
PLV press pits	25,000	12,500
Veneer dryers	28,000	14,000
Misc. trenches, pits and foundations, pneumatic systems, screens, etc.	16,000	8,000
Truck dump, hopper, ramp, footings, and pit	36,000	36,000
Radial stacker and outside chip storage slab	67,500	67,500
Ring flaker and dryer feedbins	12,000	12,000
Conveyors from truck dump	4,500	4,500
Ring and roundwood flakers	15,000	10,000
Dryers, with burner and blowers	36,000	18,000
Boiler and fuel storage and handling	50,000	35,000
Roundwood feed conveyors to flakers	17,000	17,000
Dryer fuel preparation and handling	22,500	16,000
Dry flake bins and related conveyors	25,000	25,000
Blender metering bins and related conveyors	7,000	7,000
Resin and wax tanks	20,000	13,000
Press pit and hydraulic tank area	169,000	102,000
Air-compressor foundations, trenches, and miscellaneous foundations	33,800	23,000
Finger jointing, ripsaw, laminators, feeders, stackers, and miscellaneous conveyor foundations	26,000	16,000
Substations, sumps, and yard trenches	24,000	12,000
Misc. blower footings, tower footings, etc.	18,000	9,000
Total	883,300	580,500

Table 3.--Net investment required for the first 3 years for Case I and Case II

Investment	Beginning of first year		End of first year		End of second year		End of Third year		Total	
	Case I	Case II	Case I	Case II	Case I	Case II	Case I	Case II	Case I	Case II
	Thousands of dollars									
Land	300,000	180,000	600,000	360,000	87,000	53,000	0	0	987,000	593,000
Buildings	0	0	2,260,000	1,649,800	2,000,000	1,000,000	0	0	4,260,000	2,649,800
Foundations	0	0	483,300	330,500	400,000	250,000	0	0	883,300	580,500
Machinery	0	0	19,000,000	15,000,000	10,000,000	4,300,000	652,100	358,700	29,652,100	19,658,700
Cash	0	0	159,600	110,000	372,500	256,300	0	0	532,100	366,300
Inventory	0	0	0	0	254,300	140,000	963,300	559,700	1,217,600	699,700
Accounts receivable	0	0	0	0	1,375,600	740,000	4,126,800	2,219,500	5,502,400	2,959,500
Contingency and engineering	557,800	384,800	2,231,200	1,539,200	1,673,400	1,154,400	1,115,600	769,600	5,578,000	3,848,000
Net investment	857,800	564,800	24,734,100	18,989,500	16,162,800	7,893,700	6,857,800	3,907,500	48,612,500	31,355,500

Flow of Materials

The flow of materials through a factory is important to know because this determines the number and size of machines, which in turn determines machinery costs. The quantities of materials purchased can be determined from a materials flow analysis that accounts for waste, which is needed to determine operating costs. The flow of materials is useful in determining the energy required to operate the factory and the fuel recovered from combustible waste. The materials flow analysis provides a balance of materials flowing into and out of the factory as well as in and out of each operation. Such materials balance analysis is essential for determining the cost of wood and the product yields. However, materials balance diagrams are highly complex and there are many possible variations in a balance of flow because there are many combinations of materials that can be used, such as various species, whole tree vs. saw logs, and green vs. dry residues purchased. Waste factors and veneer yields vary considerably in relation to the type of raw wood supply. The flow of materials also varies, depending upon the type of product being made.

A computer program was used to compute the flow of materials through the COM-PLY factories used in this report. The detailed results of the materials flow analysis are too extensive to include in this Paper, so only a summary is presented and only for 100 percent manufacture of 2 x 8-12 joists for Case II. Readers who want the in-depth report on waste factors, product yields, and variations in materials flow that were studied can obtain it from the author.

For Case I, the particleboard press had a nominal platen size of 6 ft wide by 25 ft long, of which 72 in. of width by 300 in. of length were usable for untrimmed width of the mat. The press had 20 openings. For Case II, the nominal platen size was 6 ft wide by 17 ft long, of which 72 in. of width and 204 inches of length were usable for untrimmed width of the mat. The press had 16 openings. For both cases, there were 12 pieces of core material for 2 x 8 joists ripped from each flakeboard produced. For both cases, the presses cycled 4.4 times per hour or every 13.64 minutes. At the rate of 4.4 cycles per hour, Case I production would be 7,805 fbm per cycle and 34,342 fbm per hour and Case II would be 4,199 fbm per cycle and 18,476 fbm per hour. For 250 days at an efficiency rate of 85 percent, the annual production for Case I is 175,146,000 fbm and 94,226,500 fbm for Case II, if only 2 x 8's are produced.

The flow of materials occurs in three production lines. One line produces the veneer portion of the joists, one produces the flakeboard cores for the joists, and one laminates the veneer cords to the flakeboard cores. There is some waste generated from each production line that flows to the boiler for fuel, but some manufacturing residue is recycled and used for feedstock for the flakeboard operation. Total waste bark, wood, and flakeboard residues ranged between 607 and 633 lb/M bm of lumber produced. This waste is about 25 percent bark and was used for boiler fuel. Dry-wood volumes are assumed to be 88 percent of their corresponding green-wood volumes.

The flow of veneer is based largely on information obtained from studies by McAlister[3] to determine the grade and yield of veneer from southern pine and various hardwoods. The following tabulation summarizes some of the important ratios taken from McAlister's studies which are used to compute wood flow in the veneer line.

Ratios	Value
Linear feet of green peeler block to cubic . feet of green peeler block	1.81
Linear feet of green tree to cubic feet of green tree	2.61

[3]McAlister, Robert H.; Taras, M. A. Yield of southern pine suitable for composite lumber and panels. Res. Pap. SE-180. COM-PLY Rep. 12. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station and Washington, DC: U.S. Department of Housing and Urban Development; 1978. 15 p.

Green cubic feet of peeler block to dry cubic feet of veneer peeled	2.95
Dry cubic feet of tree to dry cubic feet of peeler block	1.21

The volume of veneer required for the end product is a fixed and a known amount. A greater volume of veneer must be peeled or dried to account for waste in various manufacturing operations. To determine the amount of timber in peeler-block form required to operate the factory, the peeled and dried veneer volume is multiplied by 2.95 to get the green-block volume. This is an example of how the ratios were used in making a materials flow analysis.

Table 4 lists the flow of wood through the veneer production line. An important amount shown in table 4 is the quantity of green tree-length timber (71.3 ft^3) required to produce a thousand board feet of COM-PLY joists. The green tree-length timber varies in size from 10 to 22 in. in diameter at breast height (d.b.h.), and the number of trees in each size class is typical for natural pine or mixed hardwood stands (see footnote 3). Trees were assumed to be cut from a 1-ft-high stump and had top diameters of 3 to 4 in. inside the bark. The timber is assumed to be No. 2 saw-log quality, so there is nothing special about the type timber purchases. Note that the dry volume of veneer resulting in cords for joists is about one-fourth of the dry-tree volume. For this example there should be approximately 232 blocks peeled into veneer at the lathe each hour.

Table 5 shows amounts of wood and flakeboard flowing through the flakeboard manufacturing line. The greatest quantity of wood for the flakeboard comes from tree tops and veneer-peeling residues. In this analysis, a small amount of bark was allowed in the product. The whole tree is converted into COM-PLY joists except for some bark and fine residues that are burned in the boiler. In this example, 478 lb of green wood or 315 lb of dry wood are flowing into the boiler for each thousand board feet of joists produced. However, the materials balance analysis shows that additional wood must be purchased from other sources. Table 5 shows that 886 lb of green roundwood or 424 bone-dry lb of mill residues are required in addition to the green tree-length timber (table 4) for a balanced flow.

The total feedstock flowing into the flakeboard line for each thousand board feet of production is 3,626 lb of green wood. Of this, 19 lb are wasted in preparing flakes, which leaves 3,607 lb for the screening operation. Along the flakeboard line, chemicals are added and waste is lost to the boiler or recycled as feedstock. Water with chemicals is added but is later lost in waste materials and as vapor during the flake-drying and board-pressing operations. The apparent increase in the flow of material through the forming operation is due to mat that is recycled through the forming stage.

Table 4.-- Flow of wood through the veneer production line for Case II

Operation	Type wood	Flow/M bm of joist	
		Cubic feet	Pounds
Log processing	Green tree-length timber[a]	71.3	3780.2
Log processing	Dry tree-length timber[a]	62.8	1808.7
Veneer peeling	Green peeler blocks[a]	58.9	3124.2
Veneer drying	Dry veneer	20.0	575.8
Laminate veneer panels	Veneer panels	19.6	564.4[b]
Cut panels into cords	Veneer cords	16.1	464.2

[a]Does not include bark.

[b]The weight of the plywood glue used to laminate veneer is excluded.

Table 5.--Flow of wood and flakeboard through the flakeboard line for Case II

Operation	Type Wood	Flow/M bm of joist: Undried weight	Flow/M bm of joist: Dried weight
		Pounds	
Flake preparation	Tree tops	656	314
	Peeling residues	1,767	845
	Tree bark	185	104
	Veneer residues	57	54
	Flakeboard residues	75	72
	Purchased residues	886	424
	Total feedstock	3,626	1,813
Screening	Wood flakes	3,607	1,805
Drying	Wood flakes	3,391	1,697
Blending	Wood flakes, resin, and wax	1,978	1,764
Forming[a]	Wood flakes, resin, and wax	2,188	1,950
Pressing	Flakeboard	1,948	1,736
Sawing into cores	Flakeboard	1,792	1,728
Cores available for laminating	Flakeboard	1,642	1,583

[a]About 10 percent of the mat is recycled in the forming stage, which accounts for an apparent increase in materials flow in this operation.

Table 6 shows the flow of materials in pounds that occurs in the final laminating stage. For analysis 3 percent of the material was assumed to be rejected because of poor quality and breakage. There are 62.5 pieces of 2 x 8-12 joists for every thousand board feet produced, and, for this example, there is 18.4758 M bm feet of 2 x 8's produced per hour or 1,155 joists to be laminated each hour. Each joist is composed of three pieces (two cords and one core). Therefore, there are 3,465 pieces of material to be handled each hour in a 2 x 8-12 laminating operation.

The flow of materials on a per-thousand-board-foot basis does not vary much from the amounts shown in tables 4 and 5 for lumber sizes 2 x 4 to 2 x 10 for veneer or flakeboard production. However, if saw logs are fed into the system instead of tree-length timber, it will require purchasing a greater amount of flakeable wood (other than saw logs) for feedstock to obtain materials balance. This other purchased wood can be green or dry, or poor or excellent quality with regard to flaking properties. The amount of water to be removed during flake drying and the fuel value of waste is affected by the moisture content of the wood purchased. The quality of purchased wood will affect the amount of wood to be flaked, screened, and burned in the boiler. Therefore, the species, type, moisture content, and quality of wood used to make COM-PLY joists can result

Table 6.--Flow of materials leaving the factory after laminating[a]

Operation and material	Flow/M bm of joist: Undried weight	Flow/M bm of joist: Dried weight
	Pounds	
Laminating cords to cores		
Veneer laminates	474	450
Flakeboard cores	1,592	1,536
Laminating adhesive (veneer to veneer)	28	12
Laminating adhesive (veneer to core)	17	7

[a]3 percent of the final product was assumed to be rejected because of breakage or poor quality. To obtain the flow of materials into the laminating line, divide the quantities shown by 0.97.

in substantial variations in flow of materials from the amounts shown in tables 4 and 5.

Operating Costs

Operating costs are major determinants of annual net earnings or cash proceeds from the investment. In this study, based on operating costs at 1979 prices, the assumption is that the factory operated 5 days per week and 50 weeks per year. Out of each 24-hour day, it is assumed that there are 20.4 hours of useful work. Efficiency is thus 85 percent or 5,100 hours of production at full machine rate per year. The veneer and flakeboard lines should operate at a higher efficiency because essentially only a single item is made on those lines and the setup and startup times are small.

Unit Materials Cost

Wood. For wood requirements, manufacturers of COM-PLY joists can (1) purchase veneer of the grade required for joists and mill residue at lowest cost available for the flakes in the flakeboard, or (2) purchase tree-length timber and peel veneer of the quality needed from that portion of the tree with a diameter of 10 in. d.b.h. or larger. The peeling residues and portions of the tree too small to peel are then converted into flakes for the flakeboard. Tree-length timber has distinct advantages which offset its disadvantages, and is the type used in this study.

One advantage of using tree-length timber is that flakes converted from residues are of higher quality than those made from mill residues typically used in particleboard, and with relatively little waste. It is assumed that wood residues generated from trimming veneer into panel widths and panel trimming are used in the flakeboard core. When computing veneer requirements, veneer lost during manufacture is about 22 percent, but nearly all of it can be converted into wood flakes for the core.

The most important advantage to using full-length trees is that wood particles of optimum size and shape can be made from residues. Particles made by chipping roundwood and then milling the chips into flakes are ideal for COM-PLY joists. Much less resin is required to coat large flakes (up to 2 in. long) than to coat particles made from sawmill residues, which typically contain a large percentage of fine material. Although more energy is required to dry flakes and splinters made from green wood than to dry sawmill residues, this higher cost is more than offset by the reduced amounts of waste, scrap wood, and resin.

A primary advantage of tree-length timber is its cost compared to that for saw logs. Figure 3 shows the cost per cubic foot for southern pine saw logs, tree-length pine, and mixed hardwood saw logs delivered to the mill. These costs were arrived at by dividing the prices published by "Timber Mart-South" by a factor to convert the prices from dollars/M bm to cost per cubic foot. The prices are the average for 13 States in the Southern and Southeastern United States. The conversion factors used were 215.74 for pine saw logs and 242.21 for tree-length pine,[4] and 248.56 for mixed hardwood saw logs.[5] Conversion factors can vary depending on the size and quality of logs or timber purchased. Potential manufacturers of COM-PLY should use prices and conversion factors that are appropriate for their area.

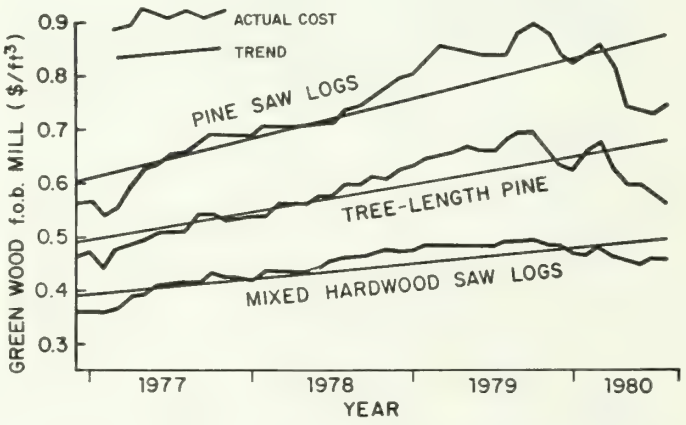

Figure 3.--Cost of wood that can be used to manufacture COM-PLY joists.

[4] Green cubic feet of log per thousand board feet, Scribner log scale.

[5] Green cubic feet of log per thousand board feet, Doyle log scale.

In 1979, the midyear trend price per cubic foot of green wood was about $0.80 for pine saw logs, $0.62 for tree-length pine, and $0.46 for mixed hardwood logs. The straight-line trend for wood cost is shown in figure 3. For this analysis the mix of wood is 50 percent tree-length pine and 50 percent mixed hardwoods. The average trendline price is $0.54 ft^3.

The other purchased wood was assumed to cost $40 per dry ton, which is about $20 per dry ton more than it would cost for whole-tree chips according to prices published in "Timber Mart-South."

Potential manufacturers of COM-PLY joists must consider all the factors discussed and select a low-cost wood supply of their own for analysis of economic feasibility. However, the quality of the COM-PLY joists with regard to strength, stiffness, durability, and dimensional stability is greatly influenced by the type of wood selected to make the flakes for the core. Therefore, performance as well as cost must be considered when determining the type and cost of wood selected.

Particleboard phenolic resin binder. Resin cost is a major expense. Figure 4 shows industrial average prices for the phenolic resin used in particleboard on a 100 percent solids basis. From 1955 to 1973 the price steadily declined; in 1974, it rose drastically as a result of shortages of petrochemicals. This study assumes the 1979 price of $0.29/lb for phenolic resin. The source of wood for panels influences the amount of resin required in cores.

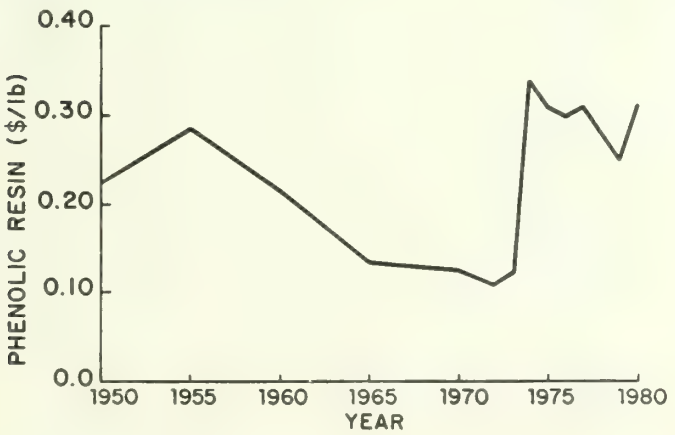

Figure 4.--Price of phenolic resin per dry pound or solids basis.

Particleboard wax. Liquid-wax emulsions are added to particleboard to reduce thickness swelling when the particleboard is soaked in water for short periods. These emulsions, roughly half wax solids, were priced at $0.082 per liquid pound in 1979.

Laminating adhesive. The veneer components of COM-PLY joists are glued together with standard phenolic plywood glue. The 1979 cost for plywood glue was $0.09 per mixed liquid pound.

Phenol-resorcinol adhesives that cure at room temperature are widely used for laminating large structural timbers. Such adhesives are a mixture of five parts liquid phenol-resorcinol resin and one part para-formaldehyde hardener by weight. In 1979, the cost of these adhesives, when mixed, was about $0.62 per liquid pound. The adhesives contain a large percentage of resorcinol in order to allow curing at room temperature in a few hours, but the adhesive can be cured with high-frequency heating equipment in just a few minutes.

Total materials cost. The total annual cost for materials was estimated by multiplying the quantity of materials flowing for each thousand board feet of production x the annual production x the unit price of the materials. Table 7 lists each material and the weighted average materials flow for 2 x 8's and 2 x 10's that were taken from detailed materials balance analyses. Included are the unit prices for materials and the weighted average annual production for Cases I and II.

Labor Cost

Labor cost varies with the level of skill demanded of workers, fringe benefits paid, and geographic location. In this report, wage rates per hour, including fringe benefits, were: unskilled laborer, $5.75; semiskilled laborer, $6.75; skilled laborer, $7.50. These rates were reported by some forest products manufacturers as typical in the Southeastern United States during 1979.

Table 8 lists the job descriptions, number of workers, number of shifts worked, wage rate paid, hours worked per

Table 7.--Annual cost of materials for a COM-PLY joist factory for Case I and Case II

Material	Materials requirement		Unit price		Total annual cost
					.....Dollars.....
CASE I					
Wood (green tree-length)	12,103,520	ft^3	x 0.54	=	6,535,901
Wood (flakeable residue)	36,506	ton (dry)	x 40.0	=	1,460,236
Flakeboard resin	16,479,207	lb (dry)	x 0.29	=	4,778,970
Flakeboard wax	2,860,976	lb (liquid)	x 0.082	=	234,600
Veneer to veneer glue	6,327,189	lb (liquid)	x 0.09	=	569,447
Veneer to core glue	2,708,968	lb (liquid)	x 0.62	=	1,679,560
Total					15,258,714
CASE II					
Wood (green tree-length)	6,510,043	ft^3	x 0.54	=	3,515,423
Wood (flakeable residue)	20,396	ton (dry)	x 40.0	=	815,839
Flakeboard resin	9,020,021	lb (dry)	x 0.29	=	2,615,806
Flakeboard wax	1,565,963	lb (liquid)	x 0.082	=	128,409
Veneer to veneer glue	3,403,156	lb (liquid)	x 0.09	=	306,284
Veneer to core glue	1,637,140	lb (liquid)	x 0.62	=	1,015,027
Total					8,396,788

Table 8.--Estimated labor requirements for COM-PLY joist plant

Operation or job	Case I						Case II					
	Workers	Shifts	Man-days	Time worked per day	Hourly wage rate	Daily labor cost	Workers	Shifts	Man-days	Time worked per day	Hourly wage rate	Daily labor cost
	Number			Hours	Dollars		Number			Hours	Dollars	
Log handling, green and dry veneer												
Green end foreman	1	2	2	16	8.50	136.00	1	2	2	16	8.50	136.00
Log scaler	1	1	1	8	7.50	60.00	1	1	1	8	7.50	60.00
Log-lift driver	1	2	2	16	6.75	108.00	1	2	2	16	6.75	108.00
Yard utility	1	1	1	8	5.75	46.00	1	1	1	8	5.75	46.00
Log deck hydraulic crane	2	2	4	32	6.75	216.00	1	2	2	16	6.75	108.00
Barker operator	2	2	4	32	6.75	216.00	1	2	2	16	6.75	108.00
Deck man	1	2	2	16	6.75	108.00	1	2	2	16	6.75	108.00
Bucking saw	2	2	4	32	6.75	216.00	1	2	2	16	6.75	108.00
Block-lift operator	2	2	4	32	6.75	216.00	1	2	2	16	6.75	108.00
Block-lift operator	1	1	1	8	6.75	54.00	1	1	1	8	6.75	54.00
Lathe deck	2	2	4	32	6.75	216.00	1	2	2	16	6.75	108.00
Lathe operator	2	2	4	32	7.50	240.00	1	2	2	16	7.50	120.00
Green end utility	1	2	2	16	5.75	92.00	1	2	2	16	5.75	92.00
Clipper operator	2	2	4	32	6.75	216.00	1	2	2	16	6.75	108.00
Veneer stacker & green chair	3	2	6	48	5.75	276.00	2	2	4	32	5.75	184.00
Forklift	1	2	2	16	5.75	92.00	1	2	2	16	5.75	92.00
Dryer tender	1	4	4	32	5.75	184.00	1	4	4	32	5.75	184.00
Dryer feeder	2	4	8	64	5.75	368.00	1	4	4	32	5.75	184.00
Dry chair	3	4	12	96	5.75	552.00	2	4	8	64	5.75	368.00
Forklift	1	4	4	32	5.75	184.00	1	4	4	32	5.75	184.00
			75	600		3,796.00			51	408		2,568.00

Continued

Table 8.--Estimated labor requirements for COM-PLY joist plant--Continued

Operation or job	Case I						Case II					
	Workers	Shifts	Man-days	Time worked per day	Hourly wage rate	Daily labor cost	Workers	Shifts	Man-days	Time worked per day	Hourly wage rate	Daily labor cost
	Number			Hours	Dollars		Number			Hours	Dollars	
Veneer layup, ripping, and laminating												
Dry end foreman	1	3	3	24	8.50	204.00	1	3	3	24	8.50	204.00
Stock rustler	1	3	3	24	5.75	138.00	1	3	3	24	5.75	138.00
Veneer layup crew	3	3	9	72	6.75	486.00	2	3	6	48	6.75	324.00
Press operator	1	3	3	24	7.50	180.00	1	3	3	24	7.50	180.00
Press helper	1	3	3	24	6.75	162.00	0	0	0	0	.00	.00
Glue mixer	1	3	3	24	5.75	138.00	1	3	3	24	5.75	138.00
Forklift	1	3	3	24	5.75	138.00	1	3	3	24	5.75	138.00
PLV trim	1	2	2	16	6.75	108.00	1	1	1	8	6.75	54.00
Finger jointer	2	3	6	48	6.75	324.00	1	3	3	24	6.75	162.00
Forklift	1	3	3	24	5.75	138.00	0	0	0	0	.00	.00
Flakeboard end glue	1	2	2	16	6.75	108.00	1	1	1	8	6.75	54.00
Flakeboard rip	1	3	3	24	6.75	162.00	1	2	2	16	6.75	108.00
Forklift	1	3	3	24	5.75	138.00	1	3	3	24	5.75	138.00
Joist laminating line	6	3	18	144	6.75	972.00	4	3	12	96	6.75	648.00
Shipping & warehouse foreman	1	1	1	8	7.50	60.00	0	0	0	0	.00	.00
Shipping clerk	1	1	1	8	6.75	54.00	1	1	1	8	6.75	54.00
Car and truck loading	2	2	4	32	5.75	184.00	2	1	2	16	5.75	92.00
Forklift	2	3	6	48	5.75	276.00	1	3	3	24	5.75	138.00
			76	608		3,970.00			49	392		2,570.00
	Number			Hours	Dollars		Number			Hours	Dollars	
Flakeboard milling and drying, and press line												
Flakeboard foreman	1	1	1	8	8.50	68.00	1	1	1	8	8.50	68.00
Truck dump	1	1	1	8	5.75	46.00	0	0	0	0	.00	.00
Front end loader	1	3	3	24	5.75	138.00	1	3	3	24	5.75	138.00
Slasher	1	3	3	24	6.75	162.00	1	3	3	24	6.75	162.00
Drum flaker	1	3	3	24	6.75	162.00	1	3	3	24	6.75	162.00
Milling and drying operator	1	3	3	24	6.75	162.00	1	3	3	24	6.75	162.00
Forming station	1	3	3	24	6.75	162.00	1	3	3	24	6.75	162.00
Utility	1	3	3	24	5.75	138.00	1	3	3	24	5.75	138.00
Press operator	1	3	3	24	7.50	180.00	1	3	3	24	7.50	180.00
Forklift	1	3	3	24	5.75	138.00	1	3	3	24	5.75	138.00
			26	208		1,356.00			25	200		1,310.00
Miscellaneous												
Quality control technician	1	3	3	24	7.50	180.00	1	3	3	24	7.50	180.00
Boiler	1	4	4	32	5.75	184.00	1	4	4	32	5.75	184.00
Knife grinder & saw filing	1	3	3	24	10.50	252.00	1	2	2	16	10.50	168.00
Cleanup	4	4	16	128	5.75	736.00	3	3	9	72	5.75	414.00
Watchman	1	4	4	32	5.75	184.00	1	2	2	16	5.75	92.00
			30	240		1,536.00			20	160		1,038.00
	Number			Hours	Dollars		Number			Hours	Dollars	
Maintenance												
Foreman	1	4	4	32	11.00	352.00	1	2	2	16	11.00	176.00
Electrician	1	4	4	32	10.50	336.00	1	4	4	32	10.50	336.00
Electrician	2	2	4	32	10.50	336.00	1	1	1	8	10.50	84.00
Millwright	1	4	4	32	10.50	336.00	1	4	4	32	10.50	336.00
Millwright	2	3	6	48	9.50	456.00	1	3	3	24	9.50	228.00
Millwright	1	1	1	8	9.50	76.00	0	0	0	0	.00	.00
Machinist	1	1	1	8	10.50	84.00	1	1	1	8	10.50	84.00
Pipefitter	1	1	1	8	9.50	76.00	0	0	0	0	.00	.00
Parts storeroom	1	1	1	8	7.50	60.00	1	1	1	8	7.50	60.00
			26	208		2,112.00			16	128		1,304.00
Total			233	1,864		12,770.00			161	1,288		8,790.00

day, and daily labor cost for each operation. Total daily labor cost was calculated to be $12,770 for Case I and $8,790 for Case II. These sums multiplied by the 250 days worked per year are the total annual labor costs. At full production capacity, the annual labor costs at the 1979 rate are $3,192,500 for Case I and $2,197,500 for Case II.

Energy Cost

A COM-PLY joist factory requires two types of energy for its operation: electrical, to power motors in machinery, and thermal, to dry green wood and for process steam. Some operations require both types of energy, while others require only one. Actual energy costs depend on the volume of materials being processed, efficiency of the machinery, fuel type, and fuel costs.

Table 9 lists the major energy-using operations for producing composite products and shows the estimated quantities of electrical and thermal energy for a given production unit per M bm of joists produced. For example, drying chips requires 18 to 20 kWh of electrical energy for every green ton of chips processed and 1,980 Btu of thermal energy for every pound of water removed from the chips. The values for energy shown in table 9 are estimates; actual values in a factory could vary widely, depending on machine efficiency.

Table 9.--Estimated energy requirements for production of COM-PLY joists

Production operation	Production unit/M bm joists	Electrical energy per unit	Thermal energy per unit
Barking logs	Linear feet of logs	0.004 to 0.012	--
Hogging waste wood and bark	Green tons	20 to 40	--
Conveying chips, logs, etc.	Green tons	5 to 25	--
Steaming peeler blocks	Green tons	--	121,000
Log cutoff and slasher saws	Linear feet of logs	0.003	--
Log-sorting deck equipment	Linear feet of logs	0.004	--
Peeling veneer blocks on rotary lathe	Square feet of veneer	0.007	--
Veneer drying			
Electrical	Square feet of veneer	0.008	--
Thermal	Pounds of water removed	--	1,650
Conveying veneer	Square feet of veneer	0.004	--
Flaking round and waste wood	Green tons of wood	17 to 40	--
Hammermilling flakes	Green tons of chips	15 to 25	--
Drying chips			
Electrical	Green tons	18 to 20	--
Thermal	Pounds of water removed	--	1,980
Screening chips	Dry tons of chips	0.3 to 0.5	--
Blending particles with resin	Dry tons of particles	8 to 9	--
Forming particleboard mat	Dry tons of mat	5 to 6	--
Prepress mat	Square feet of mat	0.005	--
Press mat into particleboard			
Electrical	Dry tons of mat	6 to 7	--
Thermal			
Heat mat	Dry tons of mat	--	120,000 to 160,000
Heat cauls (if used)	Dry tons of mat	--	80,000 to 160,000
Heat losses			
Water evaporation	Dry tons of mat	--	80,000 to 160,000
Radiation	Dry tons of mat	--	6,000 to 12,000
Convection	Dry tons of mat	--	4,000 to 12,000
Press panels for PLV			
Electrical			
Press and prepress panels	Dry tons of panels	6 to 7	--
Thermal			
Heat panels to cure glue	Dry tons of panels	--	100,000 to 140,000
Heat cauls	Dry tons of panels	--	80,000 to 160,000
Heat losses			
Water evaporation	Dry tons of panels	--	22,000 to 44,000
Radiation	Dry tons of panels	--	6,000 to 12,000
Convection	Dry tons of panels	--	4,000 to 12,000
Finish joists	Number of joists	0.003	--
Laminate joists	Number of joists	0.015 to 0.023	466 to 694

Table 10 shows the energy computations for producing 2 x 8-12 joists for Case II. For example, the amount of green-wood flakes to be dried per M bm of joists produced is 1.7 tons, and there will be 1626.44 lb of water removed in the process. The electrical energy required is 19.8 kWh/green ton dried per M bm of joists (from table 9) x 1.7 green tons/M being dried, or 33.57 kWh/M. The thermal energy is 1,980 Btu/lb of water removed per M bm of joists (from table 9) x 1626.44 lb of water removed per M bm or 3,220,354 Btu/M bm. The total electrical and thermal power required per M bm of joist production are shown in table 9. However, the total value for electrical energy is shown to be reduced by 70 percent to account for electric motors not being operated at full-rated horsepower on a continuous basis. The electrical power ranged from between 136 to 140 kWh/M bm produced for 2 x 8's and 2 x 10's for Cases I and II. The thermal energy ranged between 48 and 49 therms/M bm of 2 x 8's and 2 x 10's for Cases I and II. Electrical power was assumed to cost $0.03/kWh and thermal energy $0.25 per therm. The total annual cost for energy was found by multiplying the amount of energy used per thousand x the weighted annual production for 2 x 8's and 2 x 10's x the unit cost for energy. However, the materials balance analysis showed that between 926 and 960 lb of green wood (607 to 633 lb, dry basis) would be available for boiler fuel for each M bm of joists produced. This fuel comes from bark, sawdust, and waste too fine to use in the product. Assuming 9,000 Btu of heat for each bone-dry pound of wood and a boiler efficiency of 70 percent, there was considerable thermal energy available from the boiler that would not need to be purchased as fossil fuel.

For Case I the annual cost for electricity was $697,636 and $2,056,846 for fossil fuel without credit for burned waste wood, or $427,740 for fossil fuel if credit is given for burned waste wood. The total annual energy cost for Case I was $1,125,376 which assumes waste wood is burned for part of the fuel. For Case II the annual cost for electricity was $379,016 and $208,750 for fossil fuel after taking credit for burned waste wood for a total annual energy cost of $587,766.

Miscellaneous Production Costs

There are various other costs associated with manufacture that need to be accounted for in operating a factory. These costs are best obtained from accounting records of an actual factory; the amounts shown in table 11 are the values used in this analysis.

Sales promotion expenses were arbitrarily assumed to be $1,506,000 for Case I and $810,000 for Case II and were distributed over the first 3 years of operation in uniformly declining amounts. The 5 percent selling expense listed in table 11 is assumed to include a sufficient amount for promotional expense required after the product is introduced to the market.

Table 12 lists the personnel and salaries for Cases I and II. The total annual administrative costs at 1979 levels are $279,500 for Case I and $228,500 for Case II. Only 50 percent of the salaries were paid during the first year when there was no plant production.

Depreciation Cost

Depreciation must be computed to determine the manufacturing costs, taxable income, and return on investment. The straight-line method of depreciation was used to determine manufacturing cost and the sum-of-the-years digit method for return on investment.

Annual Sales, Operating Cash Flow, and Total Manufacturing Cost

This section shows the cash proceeds or net earnings that accrue as a result of manufacturing operations. Net earnings are computed from sales revenue minus manufacturing costs and taxes. For this analysis, assumptions are zero production the 1st year (because of plant construction), 20 percent the 2nd year, 80 percent the 3rd year, and 100 percent the 4th through the 10th year.

Table 10.--Energy required per M bm to make COM-PLY joists, Case II

Operation	Energy unit		Materials unit		Energy/hour	
					Electrical	Thermal
					kWh	Btu
Barking logs	0.007	x	106.68	=	0.75	--
Hogging fuel	33.000	x	.47	=	15.64	--
Conveying wood	13.000	x	2.29	=	29.73	--
Steaming blocks	121,000.000	x	1.56	=	--	189,012
Log cutoff	.003	x	186.14	=	.56	--
Log sorting	.004	x	186.14	=	.74	--
Peeling veneer	.007	x	959.03	=	6.71	--
Veneer drying	.008	x	959.03	=	7.67	--
Veneer drying	1,650.000	x	598.85	=	--	988,099
Conveying veneer	.004	x	959.03	=	3.84	--
Patching panels	.001	x	.00	=	.00	--
Flaking wood	29.000	x	1.81	=	52.57	--
Hammermilling	22.000	x	.84	=	18.40	--
Drying chips	19.800	x	1.70	=	33.57	--
Drying chips	1,980.000	x	1,626.44	=	--	3,220,354
Screening chips	.500	x	1.80	=	.90	--
Blending	8.800	x	.99	=	8.71	--
Forming mat	5.500	x	1.09	=	6.02	--
Prepress mat	.005	x	102.00	=	.51	--
Pressing mat	6.600	x	.97	=	6.43	--
Heating mat	140,000.000	x	.97	=	--	136,379
Heating cauls	110,000.000	x	.97	=	--	107,155
Water loss	88,000.000	x	.97	=	--	85,724
Radiation loss	9,900.000	x	.97	=	--	9,644
Convection loss	8,800.000	x	.97	=	--	8,572
Finish panels	.005	x	.00	=	.00	--
Finish lumber	.003	x	62.50	=	.19	--
Laminate lumber	.015	x	62.50	=	.94	--
Laminate lumber	466.000	x	62.50	=	--	29,125
Press veneer	6.600	x	.29	=	1.88	--
Heat veneer	100,000.000	x	.29	=	--	28,503
Heat cauls	80,000.000	x	.29	=	--	22,802
Water loss	22,000.000	x	.29	=	--	6,271
Radiation loss	9,900.000	x	.29	=	--	2,822
Convection loss	8,800.000	x	.29	=	--	2,508
					195.75	4,836,970
					x .70[a]	
					137.03	

[a]Electrical energy is 70 percent of total in order to account for motors not running at full-rate horsepower.

Table 11.--Values for computing miscellaneous production costs in operating a COM-PLY factory

Item	Percent of sales	Percent of land, buildings, and facilities cost
Production supplies	2.0	--
Maintenance supplies	1.5	--
Utilities	0.1	--
Grade-certification fees	1.0	--
Other office administrative expenses	0.7	--
Facilities maintenance	--	2.0
Facilities taxes	--	2.0
Facilities insurance	--	1.0
Sales expense	1.0	--
Contingency expense	2.0	--

Table 12.--Personnel and salaries required to operate a COM-PLY joist factory

Personnel	Case I		Case II	
	Number of people	Salary (dollars)	Number of people	Salary (dollars)
General manager	1	35,000	1	35,000
Office manager	1	30,000	0	0
Comptroller	1	27,500	1	27,500
Production manager	1	27,500	1	27,500
Technical director	1	25,000	1	25,000
Maintenance superintendent	1	25,000	1	25,000
Wood buyers	1	22,500	1	22,500
Purchasing agent	1	24,000	1	24,000
Office clerks	6	63,000	4	42,000
Total	14	279,500	11	228,500

The cost for various items are assumed to escalate throughout the investment period. The inflation rates used in this analysis are:

Item	Compound inflation rate
Wood	1.08
Particleboard resin and wax	1.04
Labor	1.065
Power	1.09
Sales and items expressed as a percentage of sales	1.08
All other items	1.06

The Federal income tax assumed was 46 percent and the local tax rate was 4 percent, for a total tax rate of 50 percent.

Some price has to be assumed for the product. In this analysis, the prices of COM-PLY joists are assumed to compete with those of sawed No. 2 grade southern pine joists. These average annual and trend prices f.o.b. mill (fig. 5) were published by Random Lengths over the last 10 years (see footnote 2).

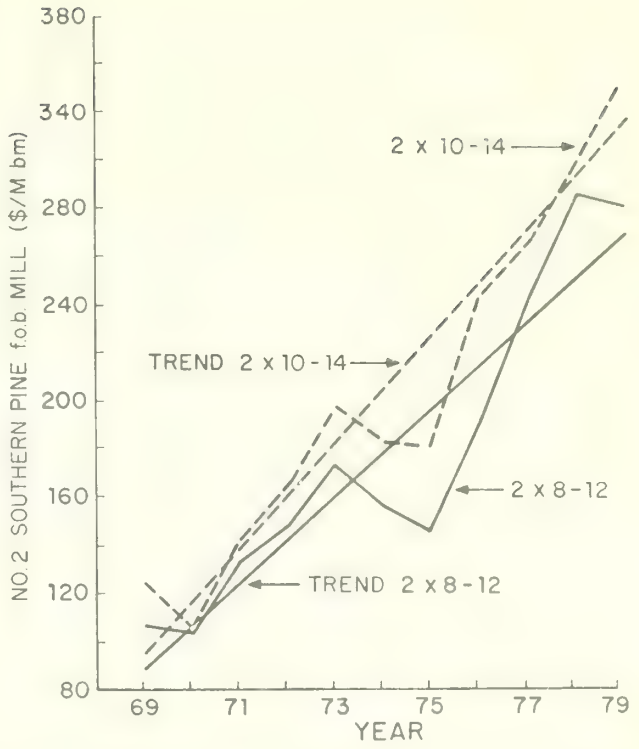

Figure 5.--Selling price f.o.b. mill for No. 2 southern pine 2 x 8 and 2 x 10 lumber.

Table 13 shows how sales were computed for the first 4 years for Case I.

Tables 14 and 15 show the annual cash flow from a COM-PLY joist factory over the 10-year investment period for Case I and Case II. Cash flow from sales was computed by multiplying the f.o.b. mill price x the board footage of joists produced per year as illustrated in table 13. When the factory reaches 100 percent production, it will be operating at an efficiency of 85 percent.

The investments for facilities and machinery were not fully depreciated during the 10-year investment period shown in tables 14 and 15. The terminal salvage value used in this report is equal to the undepreciated facilities, and machinery investment. Because terminal salvage is revenue from a sale and is taxable, it is treated as a sales item during the last year of the investment period.

Computing cash flow for manufacturing costs in tables 14 and 15 is similar to computing the cash flow for sales. Inflation rates were used to escalate costs over the 10-year period. Only 50 percent of the expense for facilities was assumed to occur the first year, but

Table 13.--Sales for first 4 years of the investment period, Case I

Year and item	Annual production rate		Price f.o.b. mill[a]		Plant production		Total sales per year
	M board feet		Dollars per M		Factor		M dollars
1979							
2 x 8-12	76,370	x	270.00	x	0	=	0
2 x 10-14	93,342	x	317.00	x	0	=	0
1980							
2 x 8-12	76,370	x	291.60	x	0.2	=	4,453.0
2 x 10-14	93,342	x	342.36	x	.2	=	6,391.3
							10,845.2
1981							
2 x 8-12	76,370	x	314.93	x	.8	=	19,240.9
2 x 10-14	93,342	x	369.75	x	.8	=	27,610.4
							46,851.3
1982							
2 x 8-12	76,370	x	340.12	x	1.0	=	25,975.3
2 x 10-14	93,342	x	399.33	x	1.0	=	37,274.0
							63,249.3

[a]Amounts shown have been rounded.

Table 14.--Cash flow from operation of a COM-PLY joist factory during a 10-year investment period, Case I[a]

Item	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
	Thousands of dollars									
A. Sales										
2 x 8	0.0	4,453.9	19,240.9	25,975.3	28,053.3	30,297.5	32,721.3	35,339.1	38,166.2	41,219.5
2 x 10	.0	6,391.3	27,610.4	37,274.0	40,255.9	43,476.4	46,954.5	50,710.9	54,767.7	59,149.1
Terminal salvage	.0	.0	.0	.0	.0	.0	.0	.0	.0	716.8
Total	.0	10,845.2	46,851.3	63,249.3	68,309.2	73,773.9	79,675.8	86,049.9	92,933.9	101,085.4
B. Raw materials										
Logs	.0	1,727.2	7,461.3	10,072.8	10,878.6	11,748.9	12,688.8	13,703.9	14,800.2	15,984.2
Phenolic resin	.0	994.0	4,135.2	5,375.7	5,590.8	5,814.4	6,047.0	6,288.8	6,540.4	6,802.0
Particleboard wax	.0	48.8	203.0	263.9	274.4	285.4	296.8	308.7	321.1	333.9
Laminating adhesive	.0	476.8	2,021.6	2,678.6	2,839.3	3,009.7	3,190.2	3,381.7	3,584.6	3,799.6
Total	.0	3,246.8	13,821.1	18,391.0	19,583.1	20,858.4	22,222.9	23,683.1	25,246.2	26,919.8
C. Production expense										
Direct labor	.0	1,020.0	2,896.8	3,856.4	4,107.0	4,374.0	4,658.3	4,961.1	5,283.6	5,627.0
Power and fuel	.0	245.3	1,069.7	1,457.4	1,588.6	1,731.6	1,887.4	2,057.3	2,242.4	2,444.2
Production supplies	.0	212.9	902.6	1,196.0	1,267.8	1,343.8	1,424.5	1,509.9	1,600.5	1,696.6
Maintenance supplies	.0	106.4	451.3	598.0	633.9	671.9	712.2	755.0	800.3	848.3
Utilities	.0	10.6	45.1	59.8	63.4	67.2	71.2	75.5	80.0	84.8
Total	.0	1,595.3	5,365.6	7,167.6	7,660.7	8,188.5	8,753.6	9,358.8	10,006.8	10,700.9
D. Administrative expenses										
General management	46.3	98.1	103.9	110.2	116.8	123.8	131.2	139.1	147.4	156.3
Office management	38.8	82.2	87.1	92.3	97.8	103.7	109.9	116.5	123.5	130.9
Clerks	54.8	116.1	123.0	130.4	138.2	146.5	155.3	164.6	174.5	185.0
Dues	.0	106.4	451.3	598.0	633.9	671.9	712.2	755.0	800.3	848.3
Other	.0	74.5	315.9	418.6	443.7	470.3	498.6	528.5	560.2	593.8
Total	139.8	477.2	1,081.3	1,349.5	1,430.5	1,516.3	1,607.3	1,703.7	1,805.9	1,914.3
E. Sales promotion	753.0	502.0	251.0	.0	.0	.0	.0	.0	.0	.0
F. Facility expenses										
Maintenance	68.0	144.2	152.8	162.0	171.7	182.0	192.9	204.5	216.8	229.8
Taxes	68.0	144.2	152.8	162.0	171.7	182.0	192.9	204.5	216.8	229.8
Insurance	34.0	72.1	76.4	81.0	85.8	91.0	96.5	102.2	108.4	114.9
Total	170.0	360.4	382.0	404.9	429.2	455.0	482.3	511.2	541.9	574.4
G. Contingency	.0	216.9	937.0	1,265.0	1,366.2	1,475.5	1,593.5	1,721.0	1,858.7	2,007.4
H. Sales expense	.0	542.3	2,342.6	3,162.5	3,415.5	3,688.7	3,983.8	4,302.5	4,646.7	5,018.4
I. Cost of operations (B+C+D+E+F+G+H+L)	1,062.7	14,109.1	30,631.9	37,475.0	38,902.9	40,483.2	42,227.4	44,147.6	46,256.7	48,568.8
J. Taxable income (A-I)	-1,062.7	-3,263.9	16,219.4	25,774.2	29,406.3	33,290.7	37,448.4	41,902.3	46,677.2	52,516.6
K. Income tax (50% x J)	-531.4	-1,631.9	8,109.7	12,887.1	14,703.2	16,645.3	18,724.2	20,951.2	23,338.6	26,258.3
L. Depreciation										
Machinery	.0	6,111.4	5,500.2	4,889.1	4,278.0	3,666.8	3,055.7	2,444.5	1,833.4	1,222.3
Facilities	.0	1,056.8	951.2	845.5	739.8	634.1	528.4	422.7	317.1	211.4
Total	.0	7,168.2	6,451.4	5,734.6	5,017.7	4,300.9	3,584.1	2,867.3	2,150.5	1,433.6
M. After-tax profit (J-K)	-531.4	-1,631.9	8,109.7	12,887.1	14,703.2	16,645.3	18,724.2	20,951.2	23,338.6	26,258.3
N. Net earnings (M+L)	-531.4	5,536.3	14,561.1	18,621.7	19,720.9	20,946.3	22,308.3	23,818.5	25,489.1	27,692.0

[a]Data may not add to totals due to rounding and truncating.

Table 15.--Cash flow from operation of a COM-PLY joist factory during a 10-year investment period, Case II[a]

Item	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
	Thousands of dollars									
A. Sales										
2 x 8	0.0	2,395.6	10,349.0	13,971.2	15,088.8	16,296.0	17,599.6	19,007.6	20,528.2	22,170.5
2 x 10	.0	3,437.6	14,850.6	20,048.3	21,652.2	23,384.4	25,255.1	27,275.5	29,457.6	31,814.2
Terminal salvage	.0	.0	.0	.0	.0	.0	.0	.0	.0	475.6
Total	.0	5,833.2	25,199.6	34,019.5	36,741.0	39,680.3	42,854.7	46,283.1	49,985.8	54,460.3
B. Raw materials										
Logs	.0	935.6	4,041.6	5,456.2	5,892.7	6,364.1	6,873.2	7,423.1	8,016.9	8,658.3
Phenolic resin	.0	544.1	2,263.4	2,942.4	3,060.1	3,182.5	3,309.8	3,442.2	3,579.9	3,723.1
Particleboard wax	.0	26.7	111.1	144.4	150.2	156.2	162.5	169.0	175.7	182.8
Laminating adhesive	.0	280.1	1,187.7	1,573.7	1,668.1	1,768.2	1,874.3	1,986.7	2,106.0	2,232.3
Total	.0	1,786.5	7,603.8	10,116.7	10,771.1	11,471.0	12,219.8	13,021.0	13,878.5	14,796.4
C. Production expense										
Direct labor	.0	702.1	1,994.0	2,654.5	2,827.0	3,010.8	3,206.5	3,414.9	3,636.9	3,873.2
Power and fuel	.0	128.1	558.7	761.2	829.7	904.4	985.8	1,074.5	1,171.2	1,276.6
Production supplies	.0	114.5	485.5	643.3	681.9	722.8	766.2	812.1	860.9	912.5
Maintenance supplies	.0	57.3	242.7	321.6	340.9	361.4	383.1	406.1	430.4	456.3
Utilities	.0	5.7	24.3	32.2	34.1	36.1	38.3	40.6	43.0	45.6
Total	.0	1,007.7	3,305.2	4,412.8	4,713.7	5,035.5	5,379.8	5,748.2	6,142.4	6,564.3
D. Administrative expenses										
General management	31.3	66.3	70.2	74.4	78.9	83.6	88.7	94.0	99.6	105.6
Office management	38.8	82.2	87.1	92.3	97.8	103.7	109.9	116.5	123.5	130.9
Clerks	44.3	93.8	99.4	105.4	111.7	118.4	125.5	133.1	141.1	149.5
Dues	.0	57.3	242.7	321.6	340.9	361.4	383.1	406.1	430.4	456.3
Other	.0	40.1	169.9	225.1	238.7	253.0	268.2	284.2	301.3	319.4
Total	114.3	339.5	669.4	818.9	868.1	920.2	975.4	1,033.9	1,095.9	1,161.7
E. Sales promotion	405.0	270.0	135.0	.0	.0	.0	.0	.0	.0	.0
F. Facility expenses										
Maintenance	42.9	90.8	96.3	102.1	108.2	114.7	121.6	128.9	136.6	144.8
Taxes	42.9	90.8	96.3	102.1	108.2	114.7	121.6	128.9	136.6	144.8
Insurance	21.4	45.4	48.1	51.0	54.1	57.3	60.8	64.4	68.3	72.4
Total	107.1	227.1	240.7	255.2	270.5	286.7	303.9	322.2	341.5	362.0
G. Contingency	.0	116.7	504.0	680.4	734.8	793.6	857.1	925.7	999.7	1,079.7
H. Sales expense	.0	291.7	1,260.0	1,701.0	1,837.1	1,984.0	2,142.7	2,314.2	2,499.3	2,699.2
I. Cost of operations (B+C+D+E+F+G+H+L)	626.4	8,795.5	17,998.8	21,790.1	22,524.6	23,344.8	24,256.9	25,267.6	26,384.2	27,614.6
J. Taxable income (A-I)	-626.4	-2,962.3	7,200.8	12,229.4	14,216.4	16,335.5	18,597.8	21,015.5	23,601.5	26,845.7
K. Income tax (50% x J)	-313.2	-1,481.1	3,600.4	6,114.7	7,108.2	8,167.7	9,298.9	10,507.7	11,800.8	13,422.8
L. Depreciation										
Machinery	.0	4,085.0	3,676.5	3,268.0	2,859.5	2,451.0	2,042.5	1,634.0	1,225.5	817.0
Facilities	.0	671.3	604.2	537.0	469.9	402.8	335.6	268.5	201.4	134.3
Total	.0	4,756.3	4,280.7	3,805.1	3,329.4	2,853.8	2,378.2	1,902.5	1,426.9	951.3
M. After-tax profit (J-K)	-313.2	-1,481.1	3,600.4	6,114.7	7,108.2	8,167.7	9,298.9	10,507.7	11,800.8	13,422.8
N. Net earnings (M+L)	-313.2	3,275.2	7,881.1	9,919.8	10,437.6	11,021.5	11,677.1	12,410.3	13,227.7	14,374.1

[a]Data may not add to totals due to rounding and truncating.

the entire expense occurred in subsequent years.

Total operating costs for tax computations were found by totaling the costs for raw materials, production, administration, sales promotion, facilities, contingencies, sales, and depreciation. For example, the operating cost for Case I in the fourth year, when full production is reached, is shown as $37,475,000. Depreciation is included with the operating cost because the Internal Revenue Service allows depreciation to be deducted as an expense for tax computations. Depreciation began in the second year, when most of the investment for machinery and facilities had been made.

The taxable income is the difference between sales and total operating costs, including depreciation. For the fourth year, the taxable income is $25,774,200. Tax on income for the fourth year is $12,887,100 and after-tax profit is $12,887,100.

To obtain the annual net earnings for the fourth year, the depreciation is added back to the after-tax profit. The net earnings for the fourth year are $18,621,700.

Notice that a negative income tax is shown for the first and second years and it would be more correct to show zero income tax for these years. The Federal Government does not make tax refunds to companies that have a loss from operating. However, a large company could charge off these losses against other parts of the business that were operating profitably; therefore, they have been left in this analysis.

Operating costs shown in tables 14 and 15 can be used to compute average 1979 manufacturing cost of joists. This cost is computed by discounting the amount for each item during the fourth year back to the 1979 cost. Total expense for sales promotion was averaged for the 10 years to give an average yearly cost for 1979. Straight-line depreciation for a 10-year period was used for computing depreciation cost for 1979. After making these adjustments, the 1979 values were divided by 169,712,000 fbm of joists produced per year for Case I and 91,882,000 fbm for Case II to obtain the cost/M ft^2. Table 16 shows the 1979 estimated manufacturing cost for COM-PLY joists for Case I and Case II.

Computing the operating costs shown in tables 14 and 15 is difficult, and accurate data are not easily obtained. Potential manufacturers of COM-PLY joists probably have a good source of data in their own company records. By using their own data and making computations similar to those shown in this section, manufacturers can accurately estimate the factory cost for their own company.

Net Cash Flow and Internal Rate of Return

Potential manufacturers of COM-PLY joists want to know what return on their investment they can expect from the cash proceeds of net earnings. The return on investment is found by determining interest rates on the basis of the present-value concept. In simple terms, if we invest $100 today at 6 percent interest, the value 1 year from today is $106. The $106 is called the future sum. The future sum includes the original amount (present value) plus interest accumulated (return on investment). The $100 is analogous to investments or cash outlays to build a factory, while the $106 is analogous to cash proceeds resulting from profitable operation.

Computing the present value of future sums at a given interest rate is referred to as discounting. In this study, the annual cash outlays (such as payout for investments) are considered as negative future sums and annual cash proceeds (such as net earnings from profitable operation) are considered as positive future sums. The object of the analysis is to find the compound interest or discount rate at which the present value of the cash outlays equals the present value of the cash proceeds. This procedure is widely used for evaluating the economic feasibility of investments and is often referred to as a discounted cash-flow analysis. The appropriate compound interest or discount rate is found by trial and error.

Table 16.--Manufacturing cost in dollars per thousand board feet of joists, Case I and Case II

Item	Case I	Case II
	Dollars	
Wood	47.1	47.4
Particleboard resin	28.2	28.7
Particleboard resin catalyst	.0	.0
Particleboard wax	1.4	1.4
Laminating adhesive	13.3	14.5
Labor	18.8	24.1
Power and fuel	6.6	6.4
Other production expense	9.2	9.2
Administrative expense	6.7	7.5
Sales promotion	.9	.9
Facilities expense	2.0	2.3
Contingency expense	5.9	5.9
Sales expense	14.8	14.8
Depreciation	19.0	23.4
Total	173.8	186.6

A low interest rate is selected and the net annual cash flow (outlay and proceeds) or future sums are converted to their present value on the basis of the rate selected. If the cumulated net annual cash flow is positive, then the present value of the cash proceeds is greater than the present value of the cash outlays for the 10 years of the investment period. In that case, a higher interest rate is selected and the procedure is repeated until a rate is found at which the positive present value of cash proceeds equals the negative present value of cash outlays. This interest or discount rate is called the internal rate of return. Internal rate of return was computed for Case I and Case II by the procedure outlined. The after-tax internal rate of return for Case I is 34.5 percent and for Case II, 27.3 percent. These are quite attractive returns on investment. Most banks would expect to see an analysis to show an after-tax return on investment of at least 25 percent before they would lend money for the investment.

In this era of high inflation, many manufacturing firms find that the price of investment capital is somewhere near 15 percent, which is about the amount they must pay to borrow for a new venture. Tables 17 and 18 show the cash flow for Cases I and II at a discount rate of 15 percent.

Column 1 in tables 17 and 18 shows the year or period of investment. Year 0 represents the beginning of year 1, but numbers 1 through 10 represent yearend times.

Column 2 shows cash outlay except for the value at year 10. This value represents working capital (cash, inventory, accounts receivable) that is recovered at the end of the investment period. The recovered working capital is treated as a positive nontaxable cash flow.

Column 3 is taken from the net earnings (tables 14 and 15). If production operations are unprofitable, the net earnings will be negative; if profitable, the net earnings are positive and represent cash proceeds.

Column 4 is the sum of columns 2 and 3 and represents net annual cash flow.

Column 5 lists the present-value factor for a 15 percent interest rate. At rates of return less than 15 percent, a company might be better off to invest elsewhere. The values in column 4 represent future sums at the end of the year indicated. By multiplying the values in column 4 by the present-value factor in column 5, the amount in column 4 is discounted (moved backward through time) to its present value (shown in column 6). For example, at the end of year 5, the net annual cash flow for Case I was $19,720,900 and the present value of annual return was $9,804,800. In other words, if we had invested $9,804,800 at time zero at a compound interest rate of 15 percent, we would have a future sum of $19,720,900 at the end of 5 years.

Column 7 shows the cumulative present value of annual cash flow in column 6. At a discount rate of 15 percent, the $48,612,500 investment in Case I would be paid back in 5.6 years. The internal rate of return is 34.5 percent. In other words, if we had used present-value factors for a discount rate of 34.5 percent, the investment would have been paid back at the end of the 10th year.

Table 17.--Discounted cash flow, payback period at 15 percent borrowing rate, and internal rate of return for a 10-year investment period, Case I

Year	Outlay (investments)	+ Proceeds (net earnings)	= Cash flow	x Present value at 15%	= Present value annual return	Cumulative present value
			Thousands of dollars			
0	-857.8	0.0	-857.8	1.0000	-857.8	-857.8
1	-24,734.1	-531.4	-25,265.5	.8696	-21,970.0	-22,827.8
2	-16,162.8	5,536.3	-10,626.5	.7561	-8,035.2	-30,863.0
3	-6,857.8	14,561.1	7,703.3	.6575	5,065.0	-25,797.9
4	.0	18,621.7	18,621.7	.5718	10,647.0	-15,150.9
5	.0	19,720.9	19,720.9	.4972	9,804.8	-5,346.1
6	.0	20,946.3	20,946.3	.4323	9,055.7	3,709.5
7	.0	22,308.3	22,308.3	.3759	8,386.5	12,096.0
8	.0	23,818.5	23,818.5	.3269	7,786.3	19,882.3
9	.0	25,489.1	25,489.1	.2843	7,245.6	27,127.9
10	8,200.4	27,692.0	35,892.3	.2472	8,872.0	35,999.9

Payback period is 5.59036 years at 15 percent borrowing rate; internal rate of return for 10-year investment period is 34.5149 percent; break-even point is 41,334.3 M bm per year.

Table 18.--Discounted cash flow, payback period at 15 percent borrowing rate, and internal rate of return for a 10-year investment period, Case II

Year	Outlay (investments)	+ Proceeds (net earnings)	= Cash flow	x Present value at 15%	= Present value annual return	Cumulative present value
			Thousands of dollars			
0	-564.8	0.0	-564.8	1.00	-564.8	-564.8
1	-18,989.5	-313.2	-19,302.7	.87	-16,784.9	-17,349.7
2	-7,893.7	3,275.2	-4,618.5	.76	-3,492.2	-20,842.0
3	-3,907.5	7,881.1	3,973.6	.66	2,612.7	-18,229.3
4	.0	9,919.8	9,919.8	.57	5,671.7	-12,557.6
5	.0	10,437.6	10,437.6	.50	5,189.3	-7,368.3
6	.0	11,021.5	11,021.5	.43	4,764.9	-2,603.4
7	.0	11,677.1	11,677.1	.38	4,389.8	1,786.5
8	.0	12,410.3	12,410.3	.33	4,056.9	5,843.4
9	.0	13,227.7	13,227.7	.28	3,760.1	9,603.5
10	4,602.7	14,374.1	18,976.8	.25	4,690.8	14,294.3

Payback period is 6.59305 years at 15 percent borrowing rate; internal rate of return for 10-year investment period is 27.3036 percent; break-even point is 27,614.7 M bm per year.

For Case II, the $31,355,500 investment would be paid back in 6.6 years. The internal rate of return for Case II is 27.3 percent.

An analysis was made of the return the owners would receive on their equity invested in Cases I and II. It was assumed that the owners provided about 25 percent of the total investment, which is a typical percentage lending institutions require. It was assumed that lending institutions would charge 15 percent interest on their part of the investment and that any cash surplus could be invested at a rate of 11 percent. The after-tax return on owners equity was 35.55 percent for Case I and 30.31 percent for Case II which is greater than the internal rate of return for both Cases I and II. Tables 19 and 20 show the detailed computations of return on owners equity for Cases I and II, respectively.

Discussion and Conclusions

This study shows that it is economically feasible to manufacture COM-PLY joists now, with a possible after-tax internal rate of return of more than 25 percent. The manufacturing cost is comparable to that for sawed lumber joists. The number of logs in the sizes required for making conventional lumber joists seems certain to decline, so there will be a ready market for the composite product.

Firms that are already manufacturing particleboard and veneer might realize greater returns by manufacturing COM-PLY joists. The conversion investment would be less than the investment for a new factory shown here, and a positive annual cash flow would occur sooner than if a new plant were built. This approach would make sense for other reasons. So many particleboard plants have been built in recent years that there is too much productive capacity in the United States. As a result, many particleboard plants in the United States are yielding a very low internal rate of return. The earning capacity of such plants could be improved by converting them to COM-PLY joist production.

Consumer demand for particleboard often peaks a year or two after peak demand for lumber, primarily because demand for lumber is greatest during a housing boom. After a housing boom subsides, the need for lumber drops off, as it did late in 1973. Subsequently, construction of shopping centers and manufacture of furniture increase, creating a strong demand for particleboard. Therefore, a manufacturer can weather market fluctuations by producing both COM-PLY joists and particleboard in one factory. A manufacturer can shift production to the product in greatest demand.

Potential manufacturers should carefully compare the manufacturing costs for COM-PLY joists with those for manufacturing sawed lumber. One of the greatest expenses in making conventional sawed lumber is the cost of wood. During periods of peak demand for lumber, the prices for stumpage increase--more so for softwoods than hardwoods. COM-PLY joists can more completely utilize the whole tree and can be made from a mixture of hardwoods and softwoods, thus easing supply pressure during periods of peak demand. If the supply of logs within a reasonable distance from a sawmill is insufficient, the mill can be forced to close. A sawmill faced with a limited timber supply could convert to composite joists and continue to operate on the limited supply of logs for many years. Conversion is possible because fewer and lower quality logs are needed for COM-PLY joists. It must be stressed that even though veneer is used in COM-PLY lumber, it does not require high-priced veneer logs for manufacture. Tree-length timber, which costs about 60 percent of veneer logs, will provide all the veneer required for manufacture and should be used instead of veneer logs. A manufacturer of COM-PLY joists has a distinct raw-materials cost advantage. Wood represents a smaller proportion of the cost of a COM-PLY joist than a sawed joist. For COM-PLY joists, the costs for resin binder, wax, and laminating adhesive is slightly greater than for wood. However, these costs are more stable and changes in them normally do not coincide with changes in wood costs nor do they rise as rapidly.

As time passes, the advantage of COM-PLY joists over conventional sawed

joists is likely to increase. Research on further improvements for composite wood products continues. Recent studies made by the Wood Products Research Unit at Athens, Ga., have demonstrated that isocyanate laminating adhesives make a quality glueline between the veneer and the core which can be clamped for as little as 30 minutes at room temperature for curing.[6] The current cost of isocyanate adhesives is slightly higher than the 1979 cost for phenol-resorcinol adhesives used in this economic analysis. However, it appears that in the future the costs will be competitive, and the short curing time without the use of costly heating equipment will reduce manufacturing costs.

Potential manufacturers also have alternate methods available for preparing the veneer. Veneer sheets can be fed into a continuous laminating press so that veneer can be butt-jointed.[7] This method would reduce labor and eliminate the finger-joint operation, would speed up production, and probably decrease the investment. Another method, which also reduces labor costs because it eliminates the finger-joint operation, is to use a long, single-opening hot-press instead of the standard multiplaten plywood press for laminating. The advantage of this method is that the veneer panels can be laid up in long lengths modular to joist lengths.

Potential manufacturers can estimate costs for alternate manufacturing procedures and materials to determine which method is most economical in relation to their equipment.

COM-PLY joists have been used in demonstration houses and builders prefer them to sawed joists because they are straight, do not warp, can be obtained in long lengths, and are more uniform in stiffness properties. The Department of HUD has accepted the COM-PLY joists performance standards. Therefore, the market and investment opportunities appear excellent for this new product.

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[6]Vick, Charles B. An emulsion polymer/isocyanate adhesive for laminating composite lumber. For. Prod. J. In press; 1984.

[7]McAlister, Robert H.; Wittenberg, Dick C. Effect of veneer butt-joint surface on the strength and stiffness of composite beams. Southeastern Forest Experiment Station, Athens, Ga. (Unpublished draft on file.)

Koenigshof, Gerald A.
Economic feasibility of manufacturing COM-PLY® floor joists. Res. Pap. SE-241. COM-PLY Rep. 26. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station and Washington, DC: U.S. Department of Housing and Urban Development; 1983. 37 p.

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COM-PLY Reports

Res. Pap.	Title and Author
SE-166	The COM-PLY Research Project. Koenigshof 1977 (Rep. 1)
SE-155	Performance Standards for Composit Studs Used in Exterior Walls. Blomquist and others 1976 (Rep. 2)
SE-163	Plywood Composite Panels for Floors and Roofs: Summary Report. Carney 1977 (Rep. 3)
SE-167	Laminating COM-PLY Studs in a Factory. Vick 1977 (Rep. 4)
SE-170	Strength and Stiffness of Composite Studs. Wittenberg 1977 (Rep. 5)
SE-171	Adhesives for COM-PLY Studs. Vick 1977 (Rep. 6)
SE-172	Durability and Dimensional Stability of COM-PLY Studs. Duff 1977 (Rep. 7)
SE-175	Structural Performance of Nailed Joints With COM-PLY. Walker 1977 (Rep. 8)
SE-179	Yield of Southern Pine Veneer Suitable for Composite Lumber and Panels. McAlister and Taras 1978 (Rep. 9)
SE-177	Demonstration Houses Built With COM-PLY Products. Koenigshof and others 1977 (Rep. 10)
SE-178	Comparative Racking Strength of Walls Framed With COM-PLY and Sawn Timber Studs. Wittenberg 1978 (Rep. 11)
SE-180	Structural Properties of COM-PLY Studs. McAlister 1978 (Rep. 12)
SE-181	Structural Performance and Standards for COM-PLY Partition Studs. Koenigshof and Wittenberg 1978 (Rep. 13)
SE-192	Performance Standards for COM-PLY Floor Joists. Duff and Wittenberg 1978 (Rep. 14)
SE-197	Economic Feasibility of Manufacturing COM-PLY Studs in the South. Koenigshof 1978 (Rep. 15)
SE-199	Structural Performance of COM-PLY Studs Made With Hardwood Veneers. McAlister 1979 (Rep. 16)
SE-201	Economic Feasibility of Manufacturing COM-PLY Panels in the South. Koenigshof 1979 (Rep. 17)
SE-207	Dimensional Stability and Durability of COM-PLY Studs Exposed to Soaking, High Humidity, and Weathering. Duff 1980 (Rep. 18)
SE-220	Evaluation of Veneer Yields and Grades From Yellow-Poplar, White Oak, and Sweetgum From the Southeast. McAlister 1981 (Rep. 19)
SE-222	End Bearing and Joint Strength of COM-PLY Joists. Wittenberg 1981 (Rep. 20)
SE-224	Linear Expansion Design Theory for COM-PLY® Panels. Talbott and others 1981 (Rep. 21)
SE-225	Resistance of COM-PLY Lumber to Subterranean Termites. Gaby and Carter 1981 (Rep. 22)
Unnumbered (In-House)	Modulus of Elasticity and Tensile Strength Distribution of Veneer of Four Commercially Important Southeastern Hardwoods. McAlister 1982 (Rep. 23)
SE-238	Veneer Yields by Grade From Three Coastal Plain Hardwoods--Blackgum, Sweetgum, and Yellow-Poplar. McAlister and Clark 1983 (Rep. 24)
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Hybridity in the *Eucalyptus grandis* Breeding Population in Florida

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Hybridity in the *Eucalyptus grandis* Breeding Population in Florida

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ABSTRACT

Some 13,000 trees were classified for apparent hybridity in a combination genetic base population and progeny test of 290 families. Included were progenies of 59 mother trees open pollinated on six Florida sites that offered hybridization opportunities. Florida mother trees averaged 14 percent hybrid progenies (with a high of 75 percent compared with 5 percent hybrid progenies from wild trees in Australia. Hybrid offspring of pure grandis mother trees significantly outperformed their pure grandis half sibs in growth, cold tolerance, and coppicing. But hybrid progenies of F_1 mother trees displayed wide segregation and generally inferior performance except in coppice traits.

Keywords: Breeding eucalypts, *Eucalyptus grandis*, exotic forestry, tree improvement.

Hybridity Among Exotic Eucalypts

Hybridity presents both problems and opportunities when eucalypts are developed as exotic timber resources outside Australia. Under favorable conditions, tree breeders can rapidly select improved local landraces thanks to the eucalypts' adaptability, rapid growth, and precocious flowering. However, these landraces are apt to contain varying degrees of interspecific hybridity.

Unintended hybridity is frequently incorporated in the first generation through tree selection and seed collection in arboreta or screening trials where small plots of different species occupy the same site. Proximity in the plots, and flowering cycles altered by the exotic climate, encourage crossing between species that are geographically, ecologically, or phenologically separated in their native habitats. Some of the resultant F_1 hybrids perform so spectacularly that they are selected for second-generation seed collection. Unfortunately their F_2 or backcross offspring often display undesirable segregation in the commercial plantations, and deepening genetic degrade in subsequent generations. Eventually the landrace expresses neither species integrity nor hybrid vigor. Classic examples are *Eucalyptus urophylla* x *E. tereticornis* in Brazil and x *E. trabutii* in Italy and North Africa.[1]

Hybridity can also be imported. Seedlots exchanged among non-Australian countries may include hybrid seed for the reasons outlined above. Australian seedlots can also contain hybrids--perhaps more often than demonstrated in natural stands, where most hybrid seed falls on sites evolutionally favoring the pure species. But as exotics, nursery culture, outplanting, and seed col-

[1]Pryor, L. D. The biology of eucalypts. London: Arnold & Company, Ltd.; 1976.

lection permit hybrids to survive, express, and reproduce.

It seems imprudent to permit uncontrolled hybridity to enter a breeding population, but it is difficult to avoid in the early stages of a new program. Most exotic eucalyptus efforts logically start with species comparison trials, so naturally the first select trees stand on multispecies sites. Even after early selection and roguing, it may not be clear as to which species is the best or only commercial choice. Thus, selects of different species are retained on the same sites with the possibility of exchanging pollen. These few early selects are too valuable to sacrifice--they are the only source of improved, locally adapted seed. Furthermore, workers in a new eucalyptus program may not be skilled at distinguishing interspecific hybridity from intraspecific variation.

The Florida breeding population of *E. grandis* Hill ex Maid. is subject to all the opportunities, risks, and sources of hybridity described above. Our grandis genetic base population established in 1973 (G-Pop73) included scores of imported seedlots in addition to advanced-generation families from early Florida test sites where hybridization was possible. G-Pop73 provided a clinical opportunity to evaluate the frequency and performance of recognizable hybrids from known mother trees.

Origins of Hybridity in Florida

Intensive trials of eucalypts in southern Florida began in the early 1960's when the Florida Forests Foundation (FFF[2]) established 10 screening trials with a total of 156 seed sources representing 67 species. *E. grandis*, *E. robusta* Sm., and *E. camaldulensis* Dehn. quickly demonstrated promise for timber production. In 1963 FFF established trial plantings of grandis, robusta, and camaldulensis on sites representing the major landtypes of southwestern Florida. All the screening and adaptation trials included multiple species, and some included obviously hybrid seedlots. Trees of more than one species were selected on most of these sites and contributed offspring to early genetic base populations.

Hybrid Potential

We first noticed the outstanding performance of hybrids in 1972 while selecting trees at a site called Silver Lake Prairie in Glades County. Planted in 1964, Silver Lake Prairie was 8.5 ha of grandis research plots including a small genetic base population of 1,562 trees of grandis and its cognate species, *E. saligna* Sm. Sources of both species included imported seedlots as well as progenies of open-pollinated selects from the original screening trial near Immokalee, Florida.

At age 7.5 years apparent F_1 hybrid trees contained an average of 191 percent more stem volume than the nonhybrid members of the same seedlots; this superiority averaged 2.2 standard deviations. Seedlot identity and morphology of the hybrids suggested four parental combinations:

Seed parents		Pollen parents
grandis or saligna	X	robusta or [robusta x redgum]

The hybrids sprung from various origins in varying frequencies:

1. Among eight grandis seedlots imported from Australia, one lot included hybrids at a 1 percent frequency; the others appeared to be pure grandis.

2. Of two imported lots of saligna, one from Spain had no hybrids, while one from Argentina produced 8 percent hybrids.

3. Of four select grandis trees in the Immokalee Screening Trial, one mother tree produced 2 percent hybrid offspring, the others none.

4. Families from four select saligna trees at Immokalee included hybrids

[2] FFF was absorbed by the U.S. Forest Service in 1967.

with a frequency range of 4 to 27 percent.

Methods

Impressed by the potential of hybrids, we inventoried our local selection sites to see which had the possibility of funneling new hybrids into G-Pop73. At Silver Lake Prairie we had selected three apparent grandis x robusta hybrids out of a seedlot from Urunga, New South Wales. We had also selected six hybrid offspring from saligna selects at Immokalee that had apparently been pollinated by either robusta or [robusta x redgum[3]]. The 9 hybrid selects at Silver Lake Prairie stood among 23 grandis selects and 1 saligna. Progenies of the hybrid selects would therefore be F_2's and backcrosses of various types.

Four seed production stands rogued from early FFF trials could potentially produce F_1 hybrids. We had left a few robusta selects standing among numerous grandis selects. Most of the robusta happened to be of the previously described segregating Spanish source. These four sites also had the potential for unintended, off-season pollen contamination from unselected redgums. Additional F_1's were also possible from grandis selects in a pilot plantation contiguous with a robusta plantation.

After the rogued stands had flowered and matured seed, we made individual-tree collections from the grandis selects on all six sites, and a composite seed collection from the hybrid selects at Silver Lake Prairie. We outplanted the resultant seedlings in the Grandis Genetic Base Population of 1973 (G-Pop73).[4]

G-Pop73 consisted of 13,230 data trees planted on 8.8 ha in Glades County. The palmetto prairie site, a mosaic of soils in the Great Group of Haplaquods, was chopped, broadcast with 2,240 kg/ha of ground rock phosphate, then bedded. Spacing was 3.7 x 1.8 m with an average of 46 trees per seedlot planted as completely randomized, single-tree plots. The total population of 290 seedlots consisted of 14 third-generation families (grandmothers selected at Immokalee or one other FFF trial); 50 second-generation families (mothers selected at 7 FFF trials); 22 first-generation Florida families (mothers of unknown origin selected on 11 Florida sites outside our breeding lines); 76 lots imported from Australia, predominantly single-tree collections from select wild trees; 111 families imported from South Africa, mostly from control-pollinated seed orchard clones; 14 seedlots imported from miscellaneous origins; and a composite lot from the hybrid selects at Silver Lake Prairie.

We measured height and scored cold damage at plantation age 6 months, and measured height and diameter at 2.4 years. At 2.7 years one observer scored each tree for branch habit and stem straightness.

The observer also scored hybridity, classifying the apparent ancestry of each tree as suggested by leaf, bark and twig characters, and occasionally aided by the odor of crushed leaves. Performance traits such as vigor and form played no part in classification. Hybridity classifications are coded as follows:

G = pure grandis
GxRb = robusta admixture
GxRg = redgum admixture--presumed camaldulensis, tereticornis or rudis
GxRR = admixtures of both robusta and redgum

This paper principally examines a subset of G-Pop73 families--progenies of 59 select grandis trees open pollinated at six Florida sites that offered hybridization possibilities, and the composite

[3]Among the several robusta pollen sources at Immokalee, a predominant one was itself a segregating hybrid lot from Spain with some individuals showing varying proportions of redgum characters such as smooth bark with the hairpin-shaped leaf scars familiar on *E. camaldulensis* and *E. tereticornis* and with leaves tending to be falcate and concolorous.

[4]Grandis sources have outperformed saligna sources in Florida tests. G-Pop73 included only 16 saligna lots compared with 271 grandis lots. We treat the two species as one breeding population dominated by grandis and referred to as the grandis base population.

progenies of 7 hybrid selects at Silver Lake Prairie.

Results and Discussion

Hybrid Frequency

Background vs. Induced Hybridity

The hybridity survey of G-Pop73 demonstrates that open pollination can produce hybrids with impressive frequency when different eucalyptus species are proximate and cross-fertile and flower synchronously. A total of 59 grandis selects bore seed on our six local sites and 55 of them (93 percent) produced some hybrid offspring. Florida mother trees averaged 14 percent hybrid progenies compared with 5 percent "background" hybridity present in families from wild trees in Australia, and also 5 percent among progenies of seed orchard clones in South Africa. The upper range of hybrid production was much higher from Florida mother trees. No Australian tree produced more than 33 percent hybrid offspring, while six Florida trees exceeded that with a high of 75 percent (table 1). Pryor[5] explains that bloom periods of grandis and robusta often converge as exotics, causing increased hybridization. Redgum was by far the most common admixture among Australian and South African families, but the Florida families showed nearly balanced admixtures (table 1).

Unfortunately, our hybridity scoring system did not consider the strength of a species' admixture, only its presence. Therefore it should not be inferred that all recorded hybridity displayed F_1 immediacy. (Hybrids among control-pollinated South African families obviously were not F_1's.) Quite subtle admixtures of redgum were "read" from persistent hairpin-shaped leaf scars and the odors of crushed leaves. Florida progenies frequently expressed intense admixture, indicating that many hybridizations occurred on our six local sites. The remainder of our report deals only with Florida families.

Hybrid Frequencies Vary Among Sites

A seed orchard designed to produce F_1 hybrids might logically consist of relatively few individuals of a designated seed species scattered widely through a matrix of many more trees of the desired pollen species. The many pollinators would be intended to flood the few seeders with interspecific pollen, while hopefully shielding the seeders from pollinating each other.

Our six hybridization sites were experiential, not experimental; none resembled a designed situation. On each site the grandis seed trees far outnumbered the select synchronous pollinators of robusta or robusta x redgum. Unselected redgums were numerous on four sites, but redgums generally bloom out of phase with grandis in southern Florida. Also, most of the grandis selects stood closer to each other than to the potential hybridizers. Therefore the hybrid frequencies achieved (table 2) probably represent the lower range that could be induced in designed, open-pollinated hybridization orchards in southern Florida.

No more than one grandis mother tree on any site failed to produce some hybrid offspring. The Babcock Palmetto Prairie, produced significantly more hybrids than the other sites (table 2), a tribute to the fecundity of that site's only select pollinator, which was itself a robusta x redgum hybrid.

Performance of Hybrids From Grandis Mother Trees

We compared the performance of grandis vs. each type of hybrid for height, stem volume, branch habit, stem straightness, and cold tolerance. At plantation age 2.9 years, we selected superior trees and rogued the based population to convert it to a seedling seed orchard. Roguing gave us the opportunity to compare the coppicing performance of grandis vs. hybrid stools.

To analyze performance, we compiled families from all six hybridization sites into a common statistical roster of 55 families. A family qualified for the roster if it had half sibs representing at least one hybrid classification in addition to its pure grandis

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[5]Pryor, L. D. Aspectos da cultura do eucalipto no Brazil. Revista IPBF Piracicabe, S. P. (Brazil), No. 2/3: 53-59.

Table 1.--Hybrid frequencies among Australian, South African, and Florida families in G-Pop73

Variable	Mother trees were--		
	Wild trees in New South Wales & Queensland	Seed orchard clones in South Africa	Select trees on six Florida hybridization sites
Number of families	76	110	59
Percentage of families with some hybrids	68	70	93
Range in percentage of hybrids per family (min., $\bar{x}$, max.)	0,5,33	0,5,35	0,14,75
Average percentage of family members classified as:			
G (pure grandis)	95.0	94.7	85.7
GxRb (robusta admixture)	.8	.6	4.1
GxRg (redgum admixture)	3.0	4.4	4.7
GxRR (robusta & redgum admixture)	1.2	.3	5.5
	100	100	100

Table 2.--Hybrid frequencies among progenies of open-pollinated grandis trees selected on six Florida sites offering hybridization possibilities

Frequency variable	Babcock Palmetto Prairie	Silver Lake Prairie	Sweet Flatwoods (deep phase)	Sweet Flatwoods (shallow phase)	Perguson'69 Plantation	FFF Headquarters
Percentage of grandis seed parents that produced some hybrid offspring	8/9=89	23/24=96	5/6=83	4/4=100	4/4=100	11/12=92
Maximum percentage of hybrids from grandis seed parent	75	48	18	24	15	12
Mean percentage of family members classified as:						
GxRb	6	5	1	2	4	2
GxRg	7	4	8	5	4	2
GxRR	18	5	1	3	2	2
$\bar{x}$ hybridity	31	14	10	10	10	6
Maximum percentage of a hybrid type in any family						
GxRb	17	37	4	6	12	6
GxRg	17	12	17	9	6	5
GxRR	50	14	4	9	6	7

trees. Statistical testing consisted of analysis of variance (ANOVA) in the randomized, complete-block model. Each ANOVA tested pure grandis vs. one class of hybrid, and blocks were those families with half sibs in the designated hybrid class. Thus, for each trait, we ran three ANOVA comparisons: G vs. GxRb, with 42 family-blocks; G vs. GxRg, 46 family-blocks; and G vs. GxRR, 33 family-blocks. Of the 55 families in the statistical roster, 22 families qualified as blocks in all three ANOVA tests, 22 in two tests, and 11 in only one test. G means from the three ANOVA tests were always nearly identical and were combined for brevity in graphs and tabulations.

Hybridization sites varied too much in quantity and quality of nongrandis pollinators to justify statistical comparisons among the three hybrid strains; therefore, ANOVAs tested only G vs. each hybrid strain. Certain variables required other statistical treatments, which are explained as encountered.

Hybrids Outgrow Grandis

At plantation age 2.4 years, hybrids stood 19 percent taller with 80 percent more stem volume than the grandis trees. All three hybrid strains grew significantly faster than their grandis half sibs (fig. 1). GxRR hybrids were superior with impressive consistency:

Percentage of families in which hybrids averaged taller than their grandis half sibs

Hybridity class		
GxRb	GxRg	GxRR
79	63	94

The modest superiority of GxRg hybrids may reflect that redgum pollen could only have come from nonselect populations on the hybridization sites. Indeed two sites, Silver Lake Prairie and Ferguson'69 Plantation, had no redgums; therefore GxRg classifications in those families reflected either distant pollinator flights or dilute hybridity from distant generations. These results do not infer that hybrids between select grandis and select redgums would be inherently less vigorous in Florida than other improved hybrids. Actually, one of our redgum base populations contains splendid examples of camaldulensis x grandis hybrids.

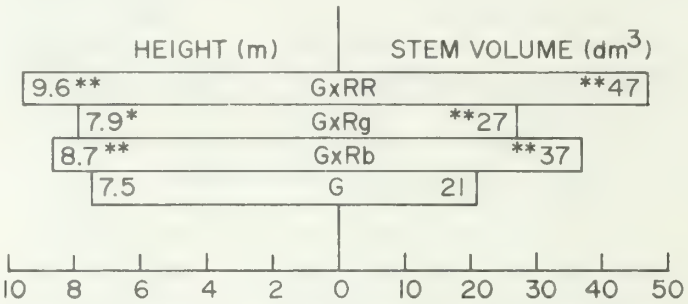

Figure 1.--Height and stem volume at age 2.4 years for grandis seedlings and their hybrid half sibs. Bars are annotated with population means. Asterisks signify that the indicated hybrid strain is larger than grandis strain at the 0.01** significance level, or the 0.05* level.

Hybridity Enhances Cold Tolerance

Four freezes in 2 weeks severely damaged G-Pop73 at age 6 months. At planting bed height, temperatures plunged to -5° C for 8 consecutive hours. Sixteen days later we estimated the proportion of each tree's foliage that still appeared functional according to the following scale:

5 = foliage functionally undamaged
4 = >75% of leaves functional
3 = 50-75% functional
2 = 25-50% functional
1 = <25% functional
0 = foliage destroyed

Trees with bark splitting on branches or trunk were scored 2 or less.

Hybrid classes combined had an average cold score of 3.5 compared with 2.9 for grandis. Differences between grandis and each hybrid strain were highly significant. RR pollen sources improved cold tolerance the most consistently and Rg pollen sources the least:

Percentage of families in which hybrid cold scores exceeded grandis cold scores

Hybridity class		
GxRb	GxRg	GxRR
71	67	91

This enhancement of cold tolerance through hybridity requires careful interpretation with the local climate. Two types of freezes threaten southern Florida, the frequent radiation freezes and the rarer blowing colds. Thermal inversions characterize radiation freezes, with temperatures coldest at ground level but moderating dramatically in the first meter or two above ground. Marginally hardy trees like *E. grandis* can reduce risk simply by growing fast--elevating tender crown tissue above lethal temperatures while building larger stems with thicker, insulative bark close to the ground. In contrast, blowing colds challenge physiological hardiness because freezing air churns through the crowns of even the tallest, mature trees. It was radiation freezing that decimated G-Pop73. The question is whether the hybrids' superior cold scores were due to faster early growth, enhanced physiological resistance, or components of both.

As we scored freeze damage, we also measured the total height of each tree's damaged crown; i.e., its prefreeze height at age 6 months. All three hybrid types stood significantly taller than their pure grandis half sibs as the freezes struck. Figure 2 illustrates that population differences in cold damage scores precisely mirrored the rank, magnitude, and significance of population differences in prefreeze height.

Trees 2 m or taller suffer little from ordinary inversion freezes, and hybrids had substantially more of those taller trees than grandis:

Percentage of seedlings with prefreeze height ≥2 m	
G	25
GxRb	39
GxRg	34
GxRR	53

The taller hybrids extended their tender tissue above lethal temperatures and were therefore challenged less severely than the generally shorter grandis. To test for physiologic differences in cold resistance, we wanted to compare grandis vs. hybrid cold scores for trees equally challenged by frost. So we pooled all families representing a hybrid type and stratified the population into five prefreeze height classes: ≤100, 100 to 149, 150 to 199, 200 to 249, and ≥250 cm. Individual trees served as completely randomized, single-tree plots.

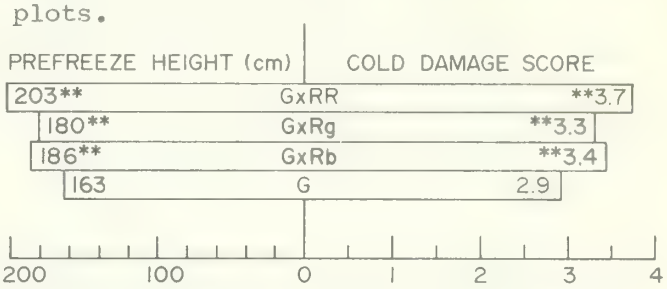

Figure 2.--Differences in cold damage from inversion freeze at age 6 months mirrored differences in prefreeze height for grandis seedlings and their hybrid half sibs. (** indicates statistical significance between grandis and hybrid means at the 0.01 level.)

First we conducted an ANOVA within each strain, testing cold score differences among the five height classes. Pure grandis and the three hybrid types all showed highly significant cold score differences among prefreeze height classes. Then we conducted ANOVAs within each height class, testing cold scores of each hybrid type against the appropriate population of pure grandis.

Figure 3 illustrates that inversion freezing sculpts dramatically different damage profiles among seedling populations of different height. Pure grandis and the three hybridity types differed little in cold score for seedlings over 2 m tall, but hybrids showed substantial superiority when prefreeze height was less than 2 m. GxRR scored significantly higher than G in all but the tallest height class; GxRb and GxRg also exceeded grandis but the differences were statistically inconsistent (fig. 3).

Apparently, hybrids had some physiological cold resistance independent of prefreeze height, but this resistance was a matter of degree, not immunity. Even the best hybrid type, GxRR, suffered about 50 percent crown destruction in the shortest height class. Nevertheless, pure grandis seedlings had to be 50 to 100 cm taller than GxRR seedlings to achieve equivalent cold scores.

Seedlings that can bolt to 2 m tall in the first 4 months after outplanting have a tremendous advantage over slower growing seedlings in coping with southern Florida's inversion freezes.

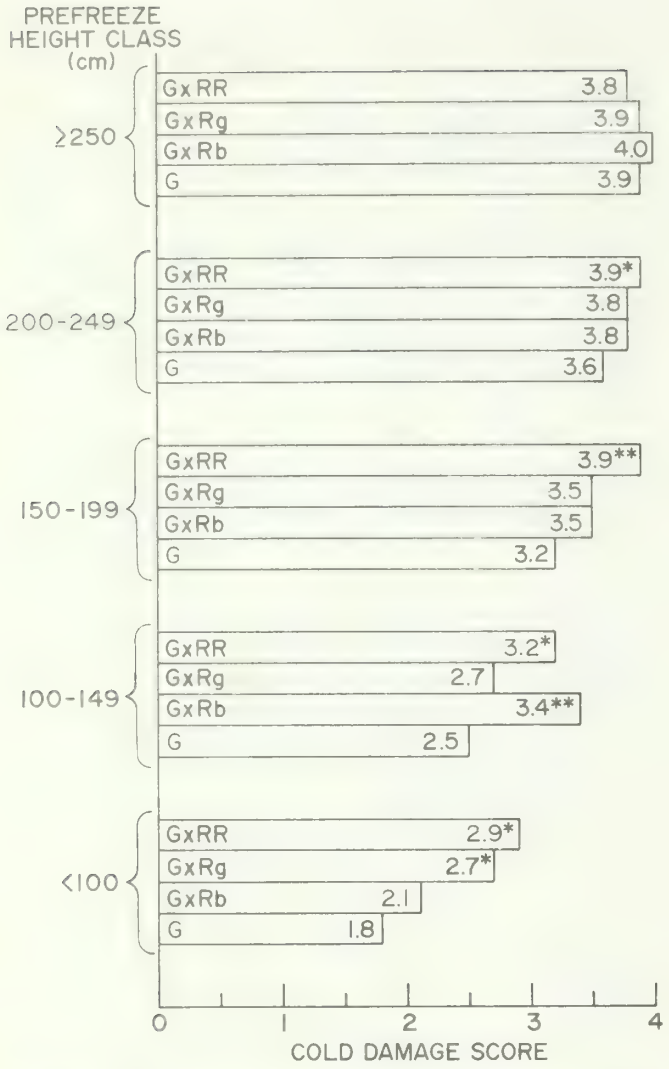

Figure 3.--Inversion freeze damage to grandis seedlings and their hybrid half sibs at age 6 months with populations stratified by prefreeze height. Within a height class, asterisks denote which hybrid strains outscored the grandis strain at the 0.05* or 0.01** significance level.

In this experience, hybrids demonstrated the requisite growth rate as well as a modest enhancement of apparent cold resistance. The superior performance of seedlings 2 m or taller confirms the prudence of ending the commercial planting season in mid-August to allow growing time before the December frost threat.

Form Altered Little by Hybridity

The observer classifying hybridity also scored the form of trees over 5 cm d.b.h. by the following system:

Branch habit: 0 = too limby for pulpwood, 1 = acceptable for pulpwood, 2 = small branched, 3 = fine branched.

Stem straightness: 0 = too crooked for pulpwood, 1 = acceptable for pulpwood, 2 = nearly straight, 3 = straight.

Grandis generally scored slightly higher than the three types of hybrids, but the advantage was statistically significant in only one of the six ANOVA comparisons, branch habit, where G averaged 1.4 compared with 1.2 for GxRR.

	Branch habit	Stem straightness
G	1.4	1.5
GxRb	1.3	1.4
GxRg	1.4	1.3
GxRR	1.2	1.4

The marginal differences in offspring form are encouraging because they suggest that grandis' splendid natural form may persist in hybrid combination with species of lesser form. Grandis selects tended to be moderately straighter and slightly finer branched than GxRb and GxRR selects, and much straighter than the unselected redgum pollinators. Redgums, however, were more finely branched than grandis.

Hybrids Superior in Coppicing

At age 2.9 years we converted the base population to a seedling seed orchard by selecting the best 431 trees (3 percent) and felling the rest with chain saws. We rogued in mid-May without the knowledge, since gained, that grandis coppices poorly during spring and summer in southern Florida[6]--seriously compromising year-round harvest.

Roguing provided an opportunity to compare coppice performance among stumps previously classified for hybridity. We evaluated coppicing success 5 months after felling, then poisoned the stumps to complete the roguing.

The relatively small numbers of hybrid stumps hampered statistical analysis of coppice variables. Consequently, we

[6]Geary, T. F.; Meskimen, G. F.; Franklin, E. C. Growing eucalypts in Florida for industrial wood production. Gen. Tech. Rep. SE-23. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1983. 43 p.

pooled all families representing each hybridity class. Survival variables (stump coppiced; stump died) were analyzed by chi-square tests; and growth variables by ANOVAs, with individual stools regarded as completely randomized, single-tree plots.

Coppice success. Only about 30 percent of grandis stumps coppiced, reflecting the seasonal problem possibly aggravated by cutting low stumps (10 cm) in anticipation of mowing the seed orchard. Hybrid coppicing significantly exceeded grandis coppicing by factors of 1.7 to 2.4 (fig. 4).

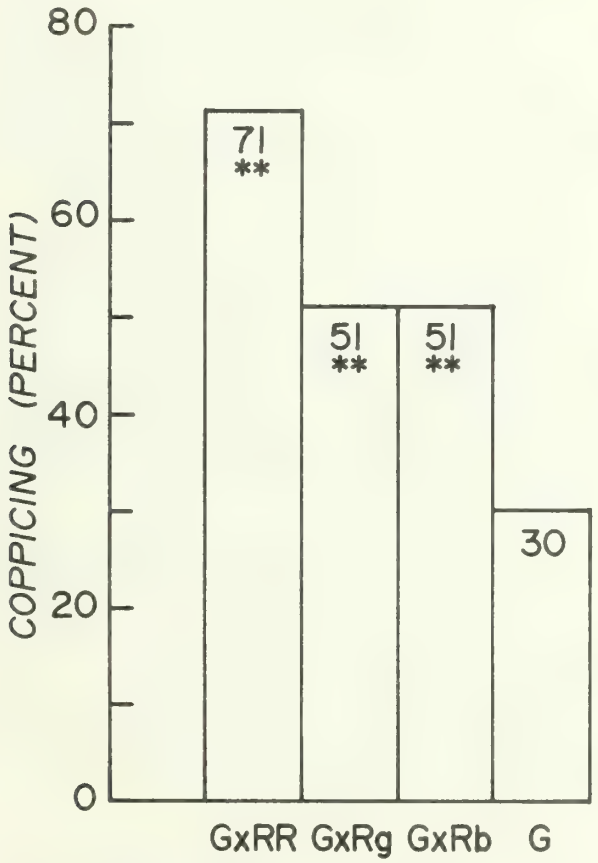

Figure 4.--Percentage of stumps coppicing successfully after felling in mid-May at age 2.9 years. Hybrid coppicing exceeded grandis coppicing at the 0.01 significance level (**, chi-squared).

Improved summer coppicing would be a valuable hybrid trait in Florida. But is coppicing superiority inherent in hybridity, or possibly a byproduct of faster hybrid growth expressed as larger average stump diameter? Is coppicing related to stump diameter? To answer these questions we stratified the populations into three stump classes based on prefelling d.b.h. at age 2.4 years. As suspected, hybrids had a much greater percentage of larger stumps:

d.b.h. (cm)	Percentage of stumps in each prefelling d.b.h. class			
	G	GxRb	GxRg	GxRR
≤5	30	14	24	6
5.1-10	62	46	58	36
>10	8	40	18	58

Chi-square testing detected significant differences (0.01 level) in coppicing success among diameter classes for pure grandis, but not for the hybrid types. All three hybrid strains coppiced better than pure grandis in all three diameter classes, but only half the differences were statistically significant (fig. 5). Notably, all three hybrids significantly exceeded pure grandis in the medium diameter class where all strains had large numbers of stumps.

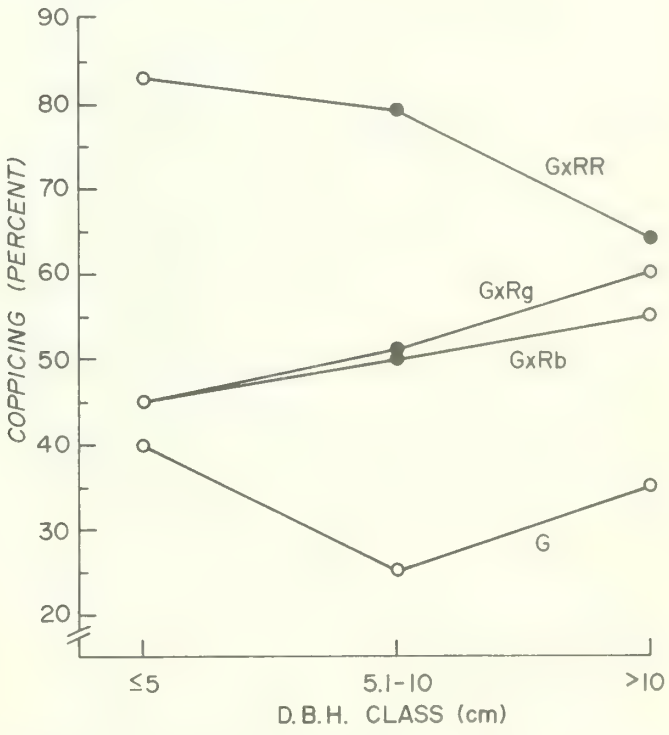

Figure 5.--Percentage of successfully coppicing stumps stratified into prefelling d.b.h. classes. Filled data points denote that, within that diameter class, coppicing percent for the indicated hybrid significantly exceeds grandis coppicing at the 0.01 level.

Coppice vigor. We assessed coppice vigor 5 months after felling by measur-

ing the tallest shoot on each stool and counting the number of firmly attached, upright shoots. Shoots numbering 1 to 8 were recorded as actual counts; 9 or more shoots were recorded as 9.

ANOVAs within each strain showed that both abundance and size of shoots were significantly depressed in the smallest prefelling diameter class for G and GxRg but not for GxRb and GxRR.

Hybrids had more and taller coppice shoots than grandis (fig. 6). GxRR was significantly superior to G for both coppice quantity and growth in all prefelling diameter classes, as was GxRb in coppice growth. Depending on diameter strata, GxRR and GxRb shoots averaged 54 to 100 percent taller than G shoots. GxRg was superior to G only in the large diameter class (fig. 6).

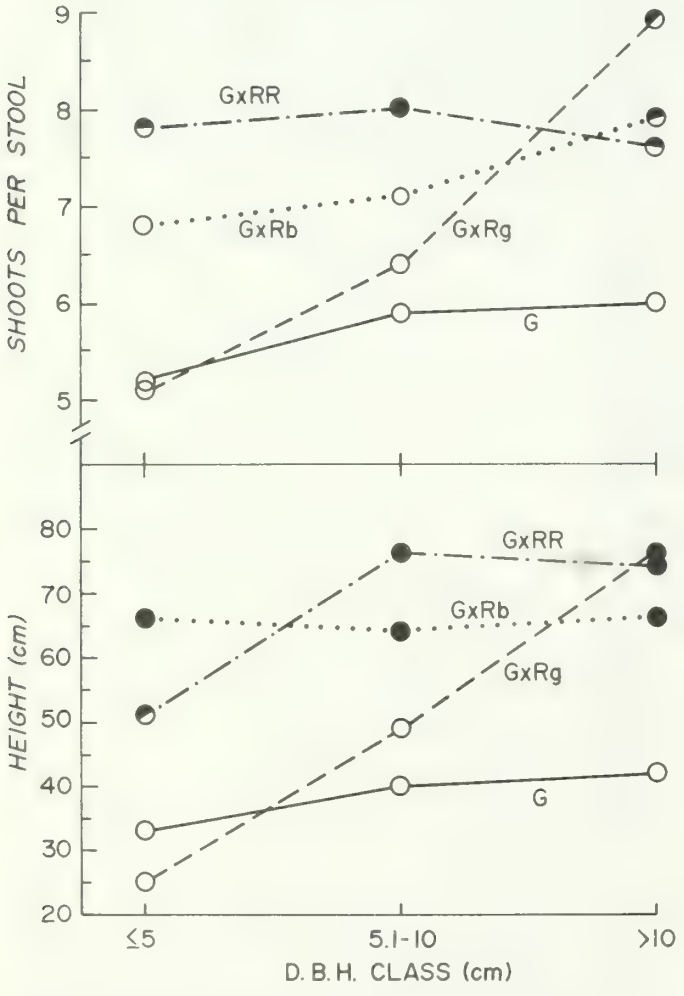

Figure 6.--Mean number of coppice shoots per stool (A) and mean height for the tallest shoot on each stool (B) 5 months after felling. Pure grandis and three hybrid populations are stratified into prefelling diameter classes. Within a diameter class, a filled data point denotes that the hybrid mean exceeds the grandis mean at the 0.01 significance level; half-filled data point, 0.05 level.

Coppice failure. More than twice as many pure grandis stumps died as lived, and hybrids were significantly more successful in summer coppicing. Stumps died in two ways: they failed to sprout, or they sprouted but the shoots died. Failure to sprout could mean that a physiologic switch is "stuck in the off position," while shoot mortality suggests insufficient stored reserves, transport failure, pathology, etc. In the pure grandis population, failure to sprout was the main cause of stump mortality by a ratio of 5.3:1. That ratio widened significantly (0.05 level) for small diameter stumps:

Pure grandis

Prefelling d.b.h. (cm)	Stump mortality ratio No shoots:Shoots died
≤5	8.1:1
5.1-10	4.7:1
>10	4.1:1

The low numbers of failed hybrid stumps prevented stratification of their failures into diameter classes. For the unstratified populations, only GxRR differed significantly (0.05 level) from G in stump mortality ratio:

	Stump mortality ratio No shoots:Shoots died
G	5.3:1
GxRb	5.7:1
GxRg	4.1:1
GxRR	2.1:1

Performance of Hybrids From Hybrid Mother Trees

As previously outlined, one hybridization site, Silver Lake Prairie, consisted of 23 grandis selects, 1 saligna select, and 9 hybrid selects. Seven hybrid selects produced seeds, which we composited and outplanted as a single entry in the genetic base population.

The seven hybrid mother trees consisted of three apparent F_1 grandis x robusta selected from one Australian grandis seedlot; and four saligna x [robusta x redgum], offspring of two saligna selects from separate seedlots

at the original Immokalee planting. Their composite progenies could have resulted from selfing, cross-fertilization among the hybrid selects, or crossing from among the 23 grandis and 1 saligna on site. In return, the hybrid selects were potential pollenizers of grandis selects. The grandis and hybrid selects were comparable in phenotypic quality; the lone saligna was the smallest select on site but still a worthy choice.

The breeding population at Silver Lake Prairie offered an opportunity to compare performances among pure species offspring, hybrid offspring from pure species mother trees, and hybrid offspring from hybrid mother trees. We pooled progeny data from 22 grandis mother trees (the 23rd produced no hybrid offspring) and the 1 saligna mother tree, and conducted ANOVA and chi-square comparisons with the composite offspring of the 7 hybrid mother trees. For brevity we code the two populations GRNPOOL and HYBCOMP, and retain the hybridity classifications G, GxRb, GxRg, and GxRR to designate either pure or hybrid progenies in GRNPOOL, or segregating progenies in HYBCOMP.

Here, it is important to amplify that the hybridity classifier assessed all 13,000 trees in the completely randomized based population independently of parental identity--without knowing if a subject tree was the offspring of a grandis or a hybrid mother tree, or even from Florida or not. Thus, the classifier could regard a subject tree in any of three ways: pure grandis (G); or grandis with discernible admixture (GxRb, GxRg, or GxRR); or even without discernible grandis.

Unbiased classification depended on parental anonymity, but interpretation requires a parental context, particularly in comparing GRNPOOL and HYBCOMP. For example, G classifications in HYBCOMP do not imply pure grandis offspring from hybrid mother trees--clearly impossible. Rather, it means that HYBCOMP segregates as G appeared as pure grandis to the classifier working without parental identity. Indeed, an F_1 grandis x robusta mother tree (three of them in the seven-tree HYBCOMP) fertilized by a grandis select would produce offspring three-fourths grandis and one-fourth robusta, and some of them might appear very grandislike. Following are the percentages of hybrids and segregates in the two populations:

	Percentage of offspring classified as:			
	G	GxRb	GxRg	GxRR
GRNPOOL	84	6	4	6
HYBCOMP	20	22	7	51

We structured ANOVA and chi-square analyses to compare progeny populations that might be produced in designed orchards. For example, by altering the composition of pollinators, pure grandis seed trees might produce exclusively pure grandis offspring; or alternatively, useful quantities of F_1 hybrids. In contrast, hybrid seed trees produce a range of segregates. Therefore, we conducted two classes of statistical comparisons: (1) a test for significant differences among HYBCOMP segregates, and (2) each strain from GRNPOOL (G, GxRb, GxRg, GxRR) compared with the HYBCOMP mean. Since the HYBCOMP mean was used in each comparison with the four GRNPOOL strains, significant differences were accepted only at the 0.01 level for individual comparisons, equivalent in this case to a 0.04 experiment-wide error rate.

Severe Hybrid Breakdown in Growth

At age 2.4 years, GRNPOOL trees stood 35 percent taller with 87 percent more stem volume than the HYBCOMP trees. Each GRNPOOL strain was statistically superior to the HYBCOMP means for both height and volume (fig. 7).

Hybrid strains within GRNPOOL demonstrated the same superiority over pure grandis, as presented earlier. In contrast, there was no superior segregate strain within HYBCOMP--only a significantly inferior segregating GxRg strain (fig. 7).

Survival at 2.4 years was 88 percent for GRNPOOL compared with 82 percent for HYBCOMP, significantly different at the 0.01 level.

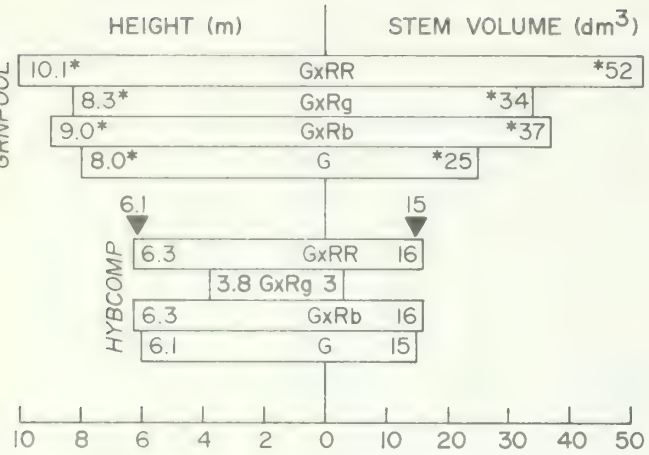

Figure 7.--Mean height and stem volume of progeny strains from grandis mother trees (GRNPOOL) compared with those of progenies from hybrid mother trees (HYBCOMP) at age 2.4 years. Pointers indicate HYBCOMP population means. Asterisks denote that all GRNPOOL strains significantly outgrew the HYBCOMP mean at the 0.04 experimentwide error rate. Highly significant differences exist among HYBCOMP's segregate strains.

Wide Segregation for Cold Tolerance

The severe hybrid breakdown in HYBCOMP growth rate was already clearly demonstrated when inversion freezes struck at age 6 months. HYBCOMP averaged 20 percent shorter than G, the shortest of the GRNPOOL strains. Nevertheless, HYBCOMP suffered no more cold damage on average than did pure grandis (fig. 8), but the GxRR strain from GRNPOOL showed significantly greater cold tolerance than the HYBCOMP. HYBCOMP varied wildly in cold tolerance as its GxRg and G segregates froze distressingly (fig. 8).

Branching Stable; Straightness Degrades

Segregate strains within HYBCOMP scored nearly the same for branch habit, and no GRNPOOL strain significantly bettered the HYBCOMP mean score. In contrast, HYBCOMP segregates differed significantly in stem straightness with G markedly superior and GxRg grossly inferior. In addition, every GRNPOOL strain except GxRg significantly outscored the HYBCOMP mean for straightness (fig. 9).

Coppicing Success Defies Hybrid Breakdown

Coppicing traits did not conform to the pattern of hybrid breakdown. Quite the contrary, 75 percent of HYBCOMP stumps coppiced successfully compared with GRNPOOL coppicing, which ranged from 68 percent for the GxRR strain down to 36 percent for G (fig. 10). Chi-square testing detected highly significant heterogeneity among HYBCOMP's segregated strains. Moreover, each segregate strain exceeded its GRNPOOL counterpart by 15 to 35 percentage points, with G the poorest coppicing strain in each population.

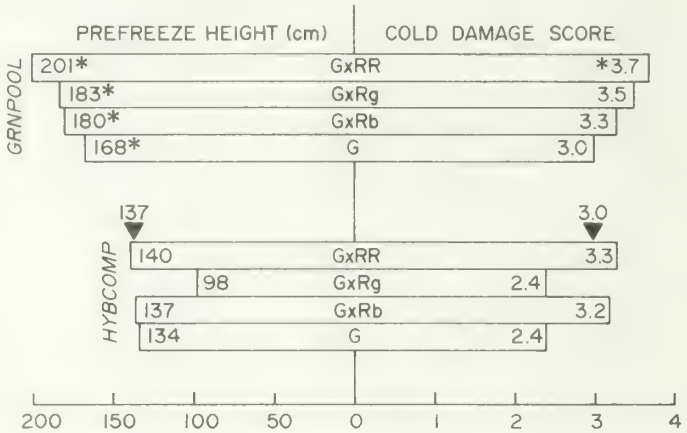

Figure 8.--Prefreeze height and cold damage from inversion freeze occurring at age 6 months. Asterisks indicate which GRNPOOL strains significantly exceed HYBCOMP means (pointers) at the 0.04 experimentwide error rate. Highly significant differences exist among HYBCOMP's segregate strains.

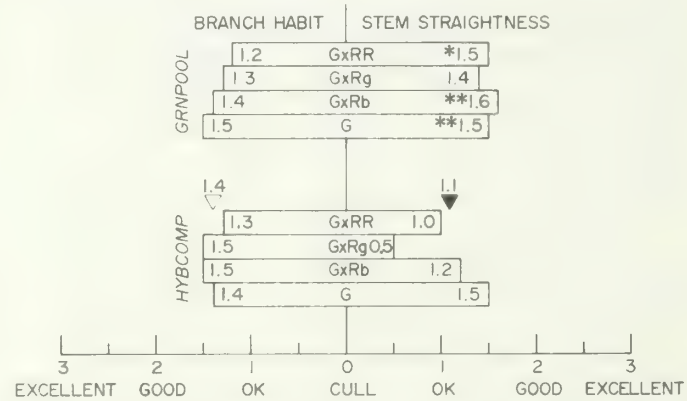

Figure 9.--Mean scores for branch habit and stem straightness at age 2.7 years. Asterisks indicate which GRNPOOL strains significantly exceed HYBCOMP means (pointers) at the 0.04 experimentwide error rate. Filled pointer denotes that highly significant differences exist among HYBCOMP's segregate strains for straightness, but not for branching.

Figure 11 illustrates that HYBCOMP also displayed no hybrid breakdown in the number of coppice shoots per stool. No GRNPOOL strain produced significantly more coppice shoots than the HYBCOMP mean; indeed GRNPOOL-G had significantly fewer shoots. Figure 11 also shows that HYBCOMP's segregate strains produced about the same number of shoots per

stool--except HYBCOMP-G, which produced significantly fewer shoots.

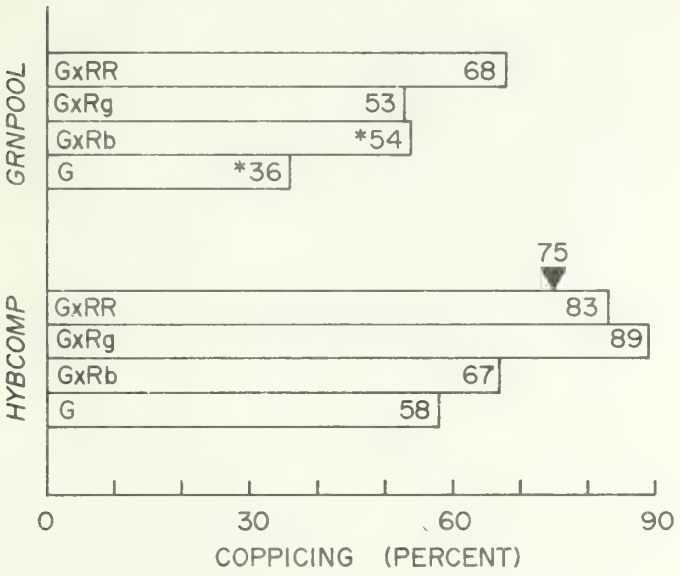

Figure 10.--Percentage of stumps coppicing successfully after felling in mid-May at age 2.9 years. Asterisks identify GRNPOOL strains with significantly less coppicing (0.04 experimentwide error rate) than the HYBCOMP mean (pointer). Highly significant differences exist among HYBCOMP's segregate strains.

HYBCOMP segregates did not differ significantly in coppice growth rate (fig. 11). GRNPOOL strains showed contrasting coppice growth relative to the HYBCOMP mean. GRNPOOL-G, mired in the summer coppicing problem, grew significantly slower than HYBCOMP, but GRNPOOL-GxRR grew significantly faster (fig. 11).

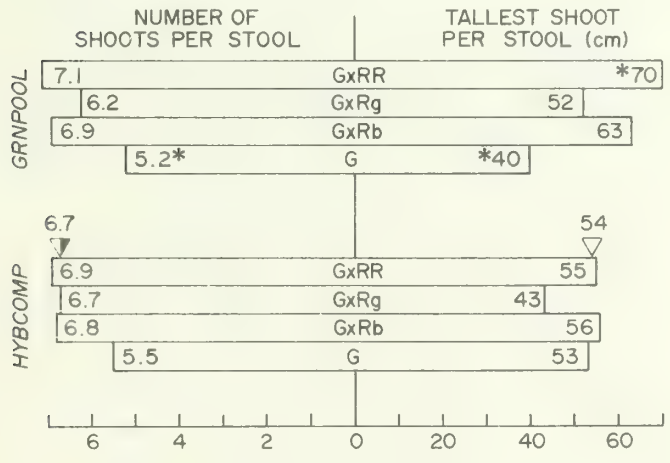

Figure 11.--Number of coppice shoots per stool and height of the tallest shoot on each stool 5 months after felling in mid-May. Asterisks denote GRNPOOL strains differing significantly from the HYBCOMP mean (pointers) at the 0.04 experimentwide error rate. Half-filled pointer signifies that significant differences (0.05 level) exist among HYBCOMP's segregate strains.

Grandis' summer coppicing is so poor that the improvement conferred by hybridity may mask any tendency toward hybrid breakdown in coppice traits. Hybrid offspring from grandis mother trees coppiced impressively better than pure grandis offspring. But in contrast to other performance traits, hybrids from hybrid mother trees coppiced even better--except for the G segregates.

Considering the myriad traits involved in tree appearance and performance, segregates among the offspring of hybrids probably intergrade along a continuum. Our hybridity classifications and statistical tests simply characterize recognizable portions of the continuum. The point is that variability was so great that characterization was easy and described meaningful performance differences. The practical importance is that seed collected from Florida's most impressive hybrid selects would produce plantations seriously degraded in growth rate and stem form, and grossly variable in appearance, cold tolerance, and summer coppicing.

Tree Selection

Before roguing G-Pop73, we conducted a tree selection without regard to hybridity classification, and prior to analysis of hybrid performance. Our selection criteria consisted of volume production, cold damage score, branch habit, and stem straightness. We were aided by computer listings of between-family and within-family rankings, but essentially we were "picking winners." It is interesting now to summarize our selections in the context of hybridity.

Data presented in the previous section make a compelling case that hybrid seedlings could make large production gains in commercial plantations--but the seed should be harvested from pure grandis mother trees. However, seedlings probably will not stock Florida's future plantations; clonal planting stock is under development. Planting hybrid ramets will require finding worthy hybrid ortets.

Frequency of Worthy Trees

At least one select tree was contributed by 96 percent of the families

representing the six hybridization sites. This percentage may seem high, but these were all advanced-generation families. Only 76 percent of first-generation Australian families contributed selects. Of the contributing Florida families, 38 percent contributed only grandis selects, 8 percent contributed only hybrid selects, and 54 percent contributed both grandis and hybrid selects.

Pooling all contributing families from all six hybridization sites, the percentages of trees chosen as selects from each hybridity classification were as follows:

G	GxRb	GxRg	GxRR
6	14	23	20

In the Silver Lake Prairie subpopulations, GRNPOOL and HYBCOMP, the selection percentages were as follows:

	G	GxRb	GxRg	GxRR
GRNPOOL strains	9	13	17	25
HYBCOMP segregates	2	0	0	3

Thus, in seeking candidates for clone testing, hybrid populations seem the more fertile fields to search, but only if they come from pure grandis mother trees.

Quality of Selects

Hybrid selects averaged larger in stem volume than the grandis selects, but only the GxRR selects were declared significantly larger by ANOVA.

	G	GxRb	GxRg	GxRR
Mean stem volume (dm^3)	55	63	58	67
Superiority over GRN (%)	--	15	5	22

A more definitive picture emerges if the stem volume of each select is scaled in terms of standard deviations above the mean volume of all GRN trees in its family. So scaled, mean deviations for the selects of each strain are:

G	GxRb	GxRg	GxRR
+1.9	+2.5	+3.1	+2.5

It is doubtful that resources will permit clone testing of all selects. Only the largest will be chosen. The largest 25 selects (of 169 contributed by grandis seed parents from the six hybridization sites) included 11 of 112 G selects, 3 of 12 GxRb selects, 4 of 22 GxRg selects, and 7 of 23 GxRR selects. Stem volumes of the largest 25 selects ranged from 162 down to 72 dm^3, compared with a mean of 59 dm^3 for all selects, and 21 dm^3 for all grandis trees.

The purpose of this investigation was limited to assessing the frequency and performance of recognizable hybrids as we encountered them in a Florida base population. The subset of families examined represents only a substantial minority of the genetic resources available to develop improved hybrid planting stock. Therefore, it is beyond the scope of this report to present breeding plans either for the mass production of hybrid seedlings or for the limited production of hybrid cloning candidates.

Summary and Conclusions

Our experience with hybridity in *E. grandis* joins other accounts of superior performance by F_1 hybrids, contrasted with hybrid breakdown among F_2's (see footnotes 1, 5). We used subjective classification to characterize apparent hybrids encountered in a large *E. grandis* breeding population in Florida. The classification system was not as rigorous as desirable. Nevertheless, results demonstrated that hybridity in an exotic eucalyptus population was easily classified into groups, and those groups performed differently in commercial traits such as growth rate, stem form, cold tolerance, and coppicing. Even a cursory classification system can be useful in controlling the risks and seizing the opportunities that hybridity presents in exotic eucalyptus programs.

Our investigation of hybrid potential was hampered by inadequate quantity, quality, and arrangement of nongrandis pollinators on the six hybridization sites. Nevertheless, the commercial promise of hybrid offspring from grandis seed trees was compellingly demonstrated by:

- hybrid frequencies as high as 31 percent from undesigned hybridization sites
- hybrids up to 28 percent taller with up to 124 percent more stem volume at age 2.4 years
- hybrid branch habit and stem straightness barely altered from pure grandis
- improved cold tolerance through early vigor and modestly enhanced physiological resistance
- summer coppicing improved by factors up to 2.4

In contrast, offspring from hybrid mother trees displayed segregation and inferior performance--with the notable exception of coppicing traits.

Clearly, eucalyptus research for southern Florida should strive to develop commercial quantities of hybrid planting stock. Two designed hybridization clusters (one utilizing clonal stock) are already established to produce candidates for clone testing, and to determine if F_1 seed of *E. grandis* x *robusta* can be mass produced by open-pollination in southern Florida.

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Meskimen, George; Franklin, E. C.
Hybridity in the *Eucalyptus grandis* breeding population in Florida. Res. Pap. SE-242. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1984. 15 p.

Hybrid offspring of pure grandis mother trees significantly outperformed their pure grandis half sibs in growth, cold tolerance, and coppicing. But hybrid progenies of F_1 mother trees displayed wide segregation and generally inferior performance except in coppice traits.

KEYWORDS: Breeding eucalypts, *Eucalyptus grandis*, exotic forestry, tree improvement.

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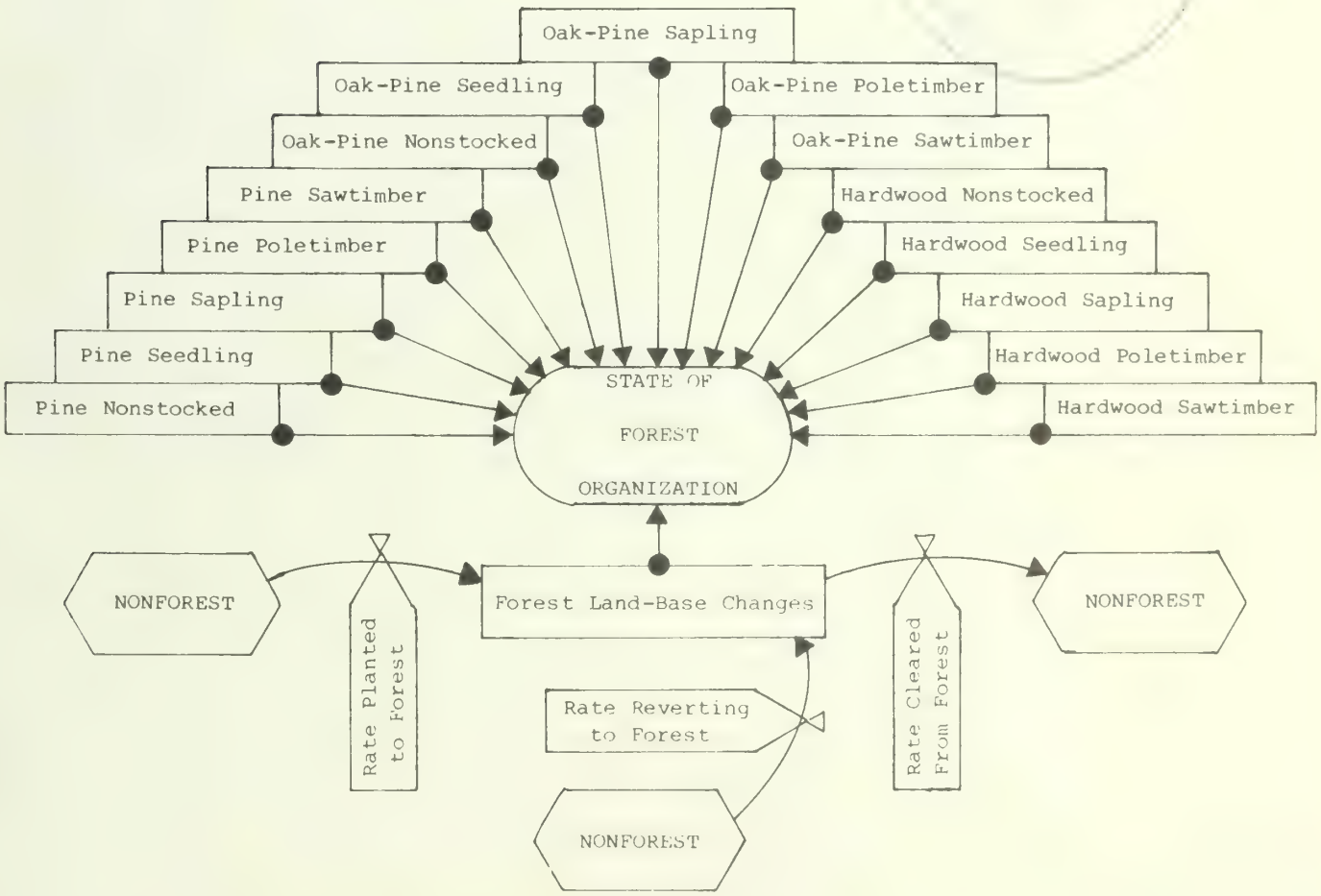
DYNARIP:
A Technique for Regional Forest Inventory Projection and Policy Analysis

William A. Bechtold



June 1984

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Asheville, North Carolina 28804

DYNARIP: A Technique for Regional Forest Inventory Projection and Policy Analysis

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ABSTRACT

This paper describes the Dynamic Regional Inventory Projection computer model (DYNARIP). DYNARIP is an area-based simulation model, written in the DYNAMO language, which projects the state of forest organization over time in terms of stand size and broad forest type. The model was developed primarily to aid legislators, regional planners, forest industry, and resource analysts assess the impacts of regional trends and forest policy decisions. The State of Georgia was selected for a pilot analysis to demonstrate how the model is built and applied.

DYNARIP is a policy-oriented model capable of tracking all of the treatments and disturbances experienced by the forest resources of an entire State or regional area. It can also isolate the impact of any one of 27 man-caused or natural disturbances (including natural succession and forest land-base changes). The model is driven by empirical rates of change as measured by forest inventories between two points in time. A few simple controls permit the entry of the user's own perceptions of the future into the model.

Keywords: Forest policy, forest simulation, forest inventory projection, resource evaluation, ecosystem dynamics.

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Introduction

Dynamic Regional Inventory Projection (DYNARIP) is an area-based forest simulation model designed to aid legislators, forest industry, regional planners, and resource analysts assess the impact of forest trends and policy decisions. DYNARIP is a policy-oriented model capable of tracking all of the treatments and disturbances experienced by the forest resources of an entire State or regional area. It can also isolate the regional effect of any one of 27 treatments or natural disturbances. This paper describes how the model works and demonstrates its use through the analysis of a forest policy issue of current concern in the State of Georgia.

Neither DYNARIP nor any other model is capable of predicting the future. Results obtained from such models are highly sensitive to basic assumptions. The forests of a region experience a diverse and independent variety of treatments and natural disturbances. The response of the resource to these disruptions is tremendously complex. In contrast to most forest models, which are driven by some form of growth equation coupled with numerous assumptions about ingrowth, mortality, and timber cut, DYNARIP is driven by empirical rates of response to treatment or disturbance as measured by forest inventories between two points in time. The assumptions necessary for the user to make thus become simplified to specifying the amount and type of acreage experiencing treatment or disturbance. The model is designed so the user's subjective perceptions can be incorporated into the model through the manipulation of a few simple controls or additional algorithms. If these perceptions are correct, DYNARIP will accurately quantify the future state of forest organization. Perhaps of equal value to the specific numbers output by the program are the trends and interrelationships that become apparent.

I. The Core Model

The DYNARIP core model projects the state of forest organization over time in terms of acres by broad forest type and stand size. Because the empirical rates of change driving the model are endemic to a given region, a new core model with unique rates must be developed for each region undergoing analysis. This concept has two advantages: Each model is built individually from data collected in the region to be analyzed, and the empirical rates of change are recalibrated each time a new inventory is conducted.

Any forest parameter that can be related to a regional forest-type/stand-size distribution can be added to the core and carried by the simulation.

DYNARIP is written in the DYNAMO language partly because the types of algorithms developed by Boyce (1980) can be used to track such nontimber benefits as wildlife habitat and recreation. DYNAMO also lends itself to integrating the complex rates of change needed to run a continuous simulation of this type (Pugh 1980; Richardson and Pugh 1981).

Model Input

DYNARIP is built with data collected during Statewide multiresource inventories. In the Southeast, forest resource data are collected on a 10-year cycle from 24,775 permanent sample plots located throughout Florida, Georgia, North Carolina, South Carolina, and Virginia (McClure and others 1979). The three main inventory classifications used as input to the model are forest type, stand size, and primary past treatment or disturbance.

The State of Georgia was selected for a pilot analysis to show how the model is built and interpreted. Similar analyses can be performed for most combinations of Survey Units in the Southeast, or for the Southeast as a whole. Data used to build the Georgia core model were screened from the fourth and fifth multiresource inventories of the State (Knight and McClure 1974; Sheffield and Knight 1984). Fieldwork for the Georgia fifth survey was

completed in 1982. A period of 10.12 years separates the two inventories.

A total of 6,134 permanent plots was used to construct the Georgia model. Sample plots were first separated into groups representing four types of acreage: acres that were forest in 1972 and remained forest over the 10-year remeasurement period, acres that were forest at the time of the initial inventory but were cleared to some nonforest land use prior to 1982, nonforest acres planted to forest between the two surveys, and nonforest acres that reverted naturally to forest. The last three categories account for forest land-base changes over the remeasurement period.

All plots were further grouped by three forest-type classifications (pine, oak-pine, and hardwood), and five stand-size classifications (nonstocked, seedling, sapling, poletimber, and sawtimber). Forest Survey determines forest type on the basis of all live trees not overtopped. Pine forest types are given to stands in which pines account for more than 50 percent of the stocking, oak-pine types to stands in which pines make up at least 25 but not more than 50 percent of live-tree stocking, and hardwood types to stands where pines constitute less than 25 percent of the stocking. In the determination of these three broad forest types, the stocking of redcedar, hemlock, spruce, and fir is included with the pines. Stand size is based on numbers of growing-stock stems per acre not overtopped. Seedlings are defined as trees less than 1.0 inch d.b.h. and saplings as trees between 1.0 and 4.9 inches d.b.h. Softwoods between 5.0 and 8.9 inches d.b.h. and hardwoods between 5.0 and 10.9 inches d.b.h. are classed as poletimber. Softwoods greater than 8.9 and hardwoods greater than 10.9 inches d.b.h. are sawtimber. Seedling through sawtimber stand sizes are assigned to whichever grouping of tree diameter classes contains the plurality of stocking. A nonstocked stand size is assigned to stands less than 16.7 percent stocked with growing-stock trees. Forest acres cleared to nonforest over the remeasurement period were assigned the forest type and stand size recorded at the time of the initial (1972) inventory. Nonforest acres planted and reverted to forest were assigned the forest type and stand size recorded at the time of the final (1982) inventory.

On forest-to-forest acres, the forest type and stand size at both the initial and final inventories were screened from plot data. These forest-to-forest plots were further ordered by the primary treatment or disturbance they experienced over the remeasurement period. During the Georgia inventory, 27 individual treatments and disturbances were recognized by Forest Survey. For this analysis, some were combined to form 13 treatment/disturbance categories. These could be rearranged or further condensed to suit individual needs. The 13 categories used for this analysis and the Survey treatment/disturbance classes included in them are listed below:

1. Natural Succession.[1] No treatment or disturbance; significant damage from weather or other natural destructive agents.

2. Harvesting Followed by Artificial Regeneration. Harvesting followed by artificial regeneration.

3. Harvesting Followed by Natural Regeneration. Harvesting followed by natural regeneration; harvesting leaving seed trees with satisfactory regeneration.

4. Harvesting Without Regeneration. Harvesting without regeneration; harvesting leaving seed trees without satisfactory regeneration.

5. Highgrading. Removal of selected trees resulting in highgrading.

6. Artificial Regeneration on Forest Land. Artificial regeneration after site preparation; artificial regeneration without site preparation.

7. Other Intermediate Cutting. Cleaning, release, or other intermediate cutting.

8. Commercial Thinning. Commercial thinning.

9. Prescribed Burning. Prescribed burning.

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[1] Although true natural succession includes damage from insects and disease, these disturbances were kept separate because they can be controlled to some extent.

10. Disease Damage. Significant damage from disease.

11. Insect Damage. Significant damage from insects.

12. Grazing. Grazing or other activity that retards or precludes development of the understory.

13. Miscellaneous Treatments/Disturbances. Turpentining; construction of woods roads, fences, firebreaks, or trash-pits; salvage cut; clearing or other site preparation; precommercial thinning; girdling or poisoning of undesirable trees; significant damage from wildfire; major drainage efforts; major man-caused flooding; other significant disturbance.

All forest-to-forest plots having the same initial forest type and stand size were arranged under each treatment/disturbance category. Resulting forest types and stand sizes as measured by the final inventory were then examined to determine the effect of each treatment on inventory dynamics. A certain percentage of these plots retained the same forest type and stand size at the time of the final inventory, but some had shifted to other type-size combinations.

Figure 1 illustrates this concept for stands which were pine poletimber at the time of initial inventory and had undergone a commercial thinning over the remeasurement period. About 39 percent were still classified as pine poletimber at the final inventory, 53 percent had moved on to pine sawtimber, and the remainder were scattered among several other type-size combinations. The dispersion pattern for pine poletimber stands experiencing other treatments or disturbances looks entirely different. For example, of all the pine poletimber stands that experienced harvesting with artificial regeneration, none remained in poletimber, 60 percent resulted in pine seedling, and 37 percent resulted in pine sapling stands by the time of the final inventory.

For each of the 13 treatment/disturbance categories, a matrix of empirical rates of change among forest type and stand-size combinations between the initial and final inventories was calculated from the plot data. Everything that happened to the forest resource is built into the rates, and it is possible to

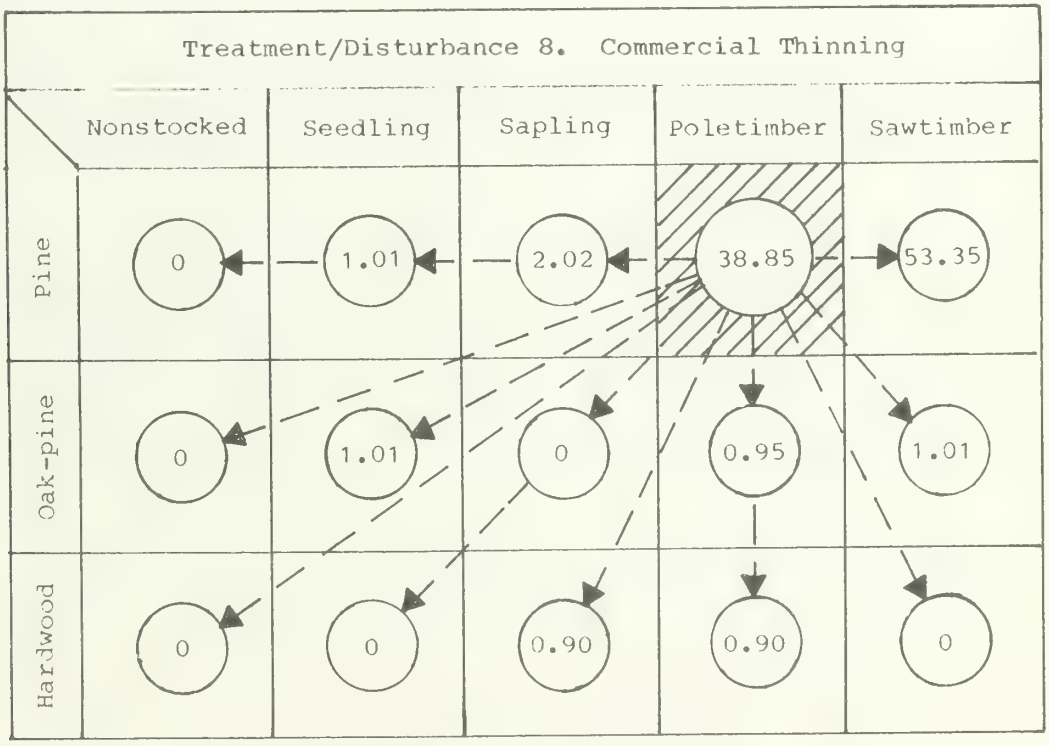

Figure 1. Percentage distribution of forest type and stand-size changes experienced over the remeasurement period by pine poletimber stands undergoing commercial thinning, Georgia, 1972-1982.

single out the effect of any of the 27 disturbances Survey recognizes. In all, 2,925 empirical rates of change were measured from all possible combinations (3 initial forest types x 5 initial stand sizes x 3 final forest types x 5 final stand sizes x 13 treatments/disturbances).

Biologicial Response to Treatment

The major premise of DYNARIP is that the matrix of type-size changes observed under a given primary treatment or disturbance captures the regional biological response of the forest to that disruption. These matrices of empirical rates are unique to a given region for a given treatment. They are recalibrated each time a new inventory is completed. The main controlling factor dictating inventory changes between two points in time is the number of acres of each type-size combination experiencing each treatment or disturbance.

DYNARIP uses this concept to build a foundation of empirical rates from recent observations upon which the model user can interject personal perceptions about the future.

Model Flow Charts

In this section, a segment of DYNARIP is flow-charted to facilitate a basic understanding of how the model works. The matrix of change for pine poletimber stands that experience treatment 8 (commercial thinning) was arbitrarily chosen for demonstration. A detailed listing of the program along with additional technical notes is provided in Appendix A.

Figure 2 illustrates how the initial pine poletimber inventory is broken down. The initial inventory is first separated at time 0 into pine poletimber acres that are to be cleared to nonforest and into pine poletimber acres that will remain in a forest condition (not necessarily pine poletimber) over the model's 10-year timespan. The cleared acres are then transferred to a level equation that keeps track of pine poletimber land-base changes. Level equations simply calculate the number of acres held in a given category at a particular instant in time. The land-base change level will be discussed in more detail later. The initial pine poletimber acres that are to remain in forest for the span of the model are then split by the percentage that are to experience treatment 8. This amount of acreage is then fed into the treatment 8 matrix of change (fig. 3). Acres enter the matrix at a linear rate determined by the total number of acres to experience treatment 8, divided by the total number of iterations in the model timespan.

As pine poletimber acres move into the treatment 8 matrix, some remain in pine poletimber, but some are dispersed to other forest-type/stand-size levels at the rates calculated from the latest Survey regional plot data. The bottom half of figure 3 illustrates dispersion from the treatment 8 pine poletimber level. Simultaneously, some of the other type-size combinations are also experiencing treatment 8. This, in turn, causes some of the acres in those levels to flow into the pine poletimber level. The top half of figure 3 represents acres converging on the treatment 8 pine poletimber level. At the end of each computational iteration the acres remaining in the treatment 8 pine poletimber level exemplify the net effect of treatment 8 on pine poletimber up to that point in time.

Upon completion of an iteration, the acreage in the treatment 8 pine poletimber level is added to the pine poletimber levels from the other 12 treatments (fig. 4). This sum, when combined with the acres in the pine poletimber land-base change level, equals the net pine poletimber inventory at that time.

At the beginning of the model run, the acres in the pine poletimber land-base change level are equal to the amount of acres that are to be cleared to nonforest over the span of the model. Acres flow out of this level at a rate determined by the total acres to be cleared, divided by the total number of iterations in the model. If this level were not being supplemented by nonforest acres planted and reverting to pine poletimber, it would be exactly zero at the end of the model run. However, it is being replenished at the rate calculated by the sum of planted and reverted acres resulting in pine poletimber, divided by the number of model iterations. If the number of acres cleared to nonforest exceeds the

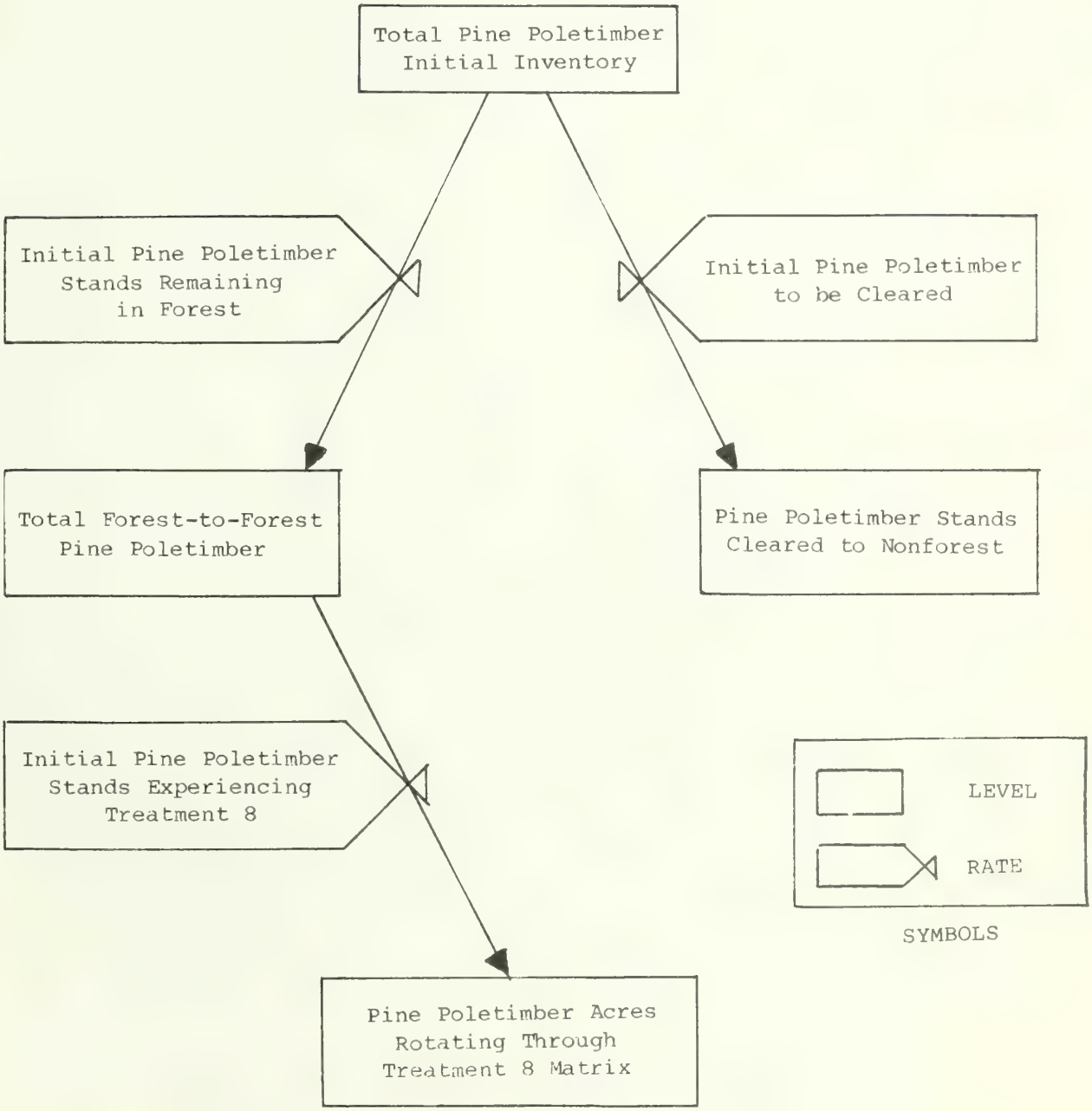

Figure 2.--Flow chart illustrating DYNARIP initial forest type and stand-size model input breakdowns, treatment 8, pine poletimber.

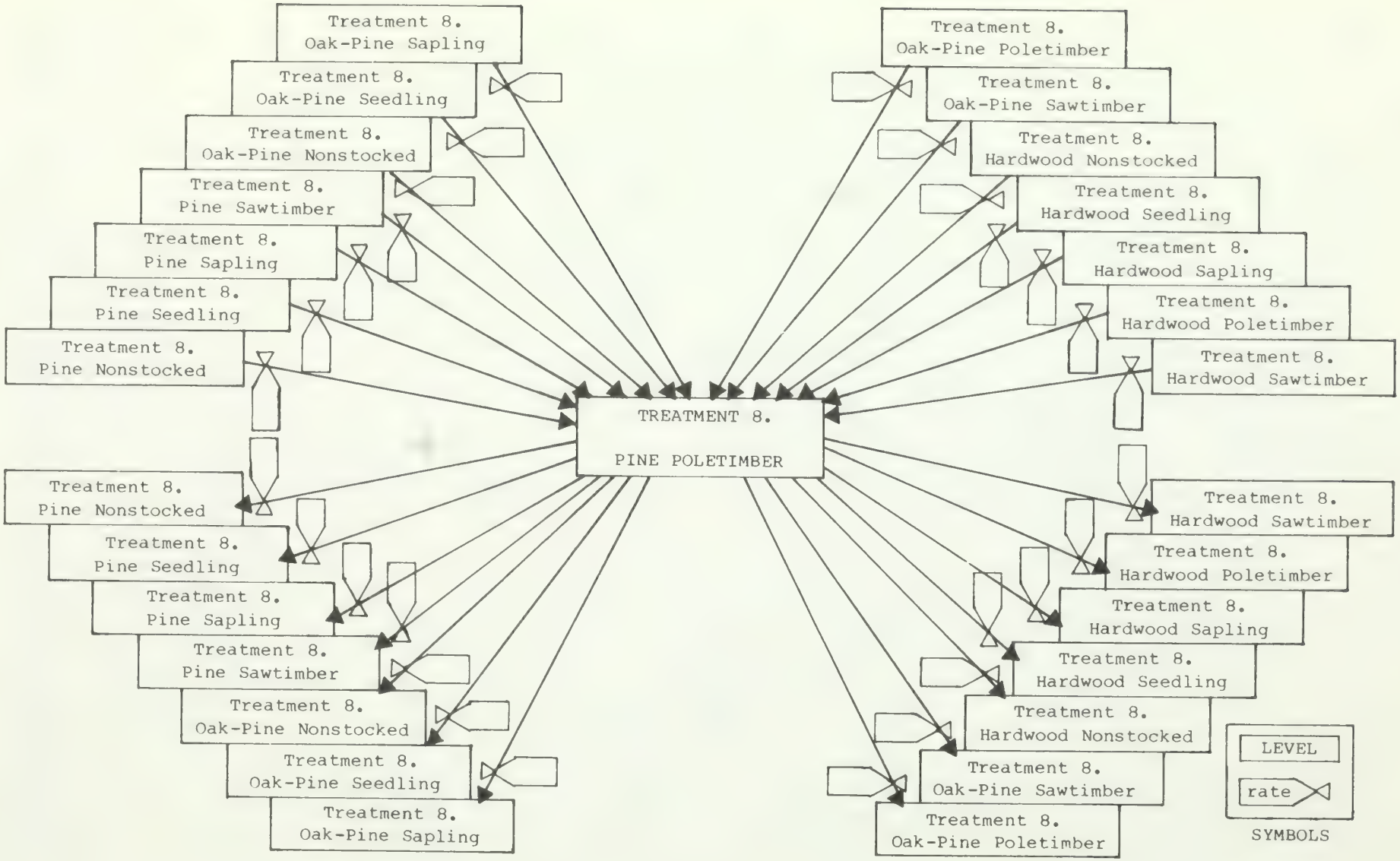

Figure 3.--Flow chart illustrating DYNARIP treatment 8 matrix of change, pine poletimber.

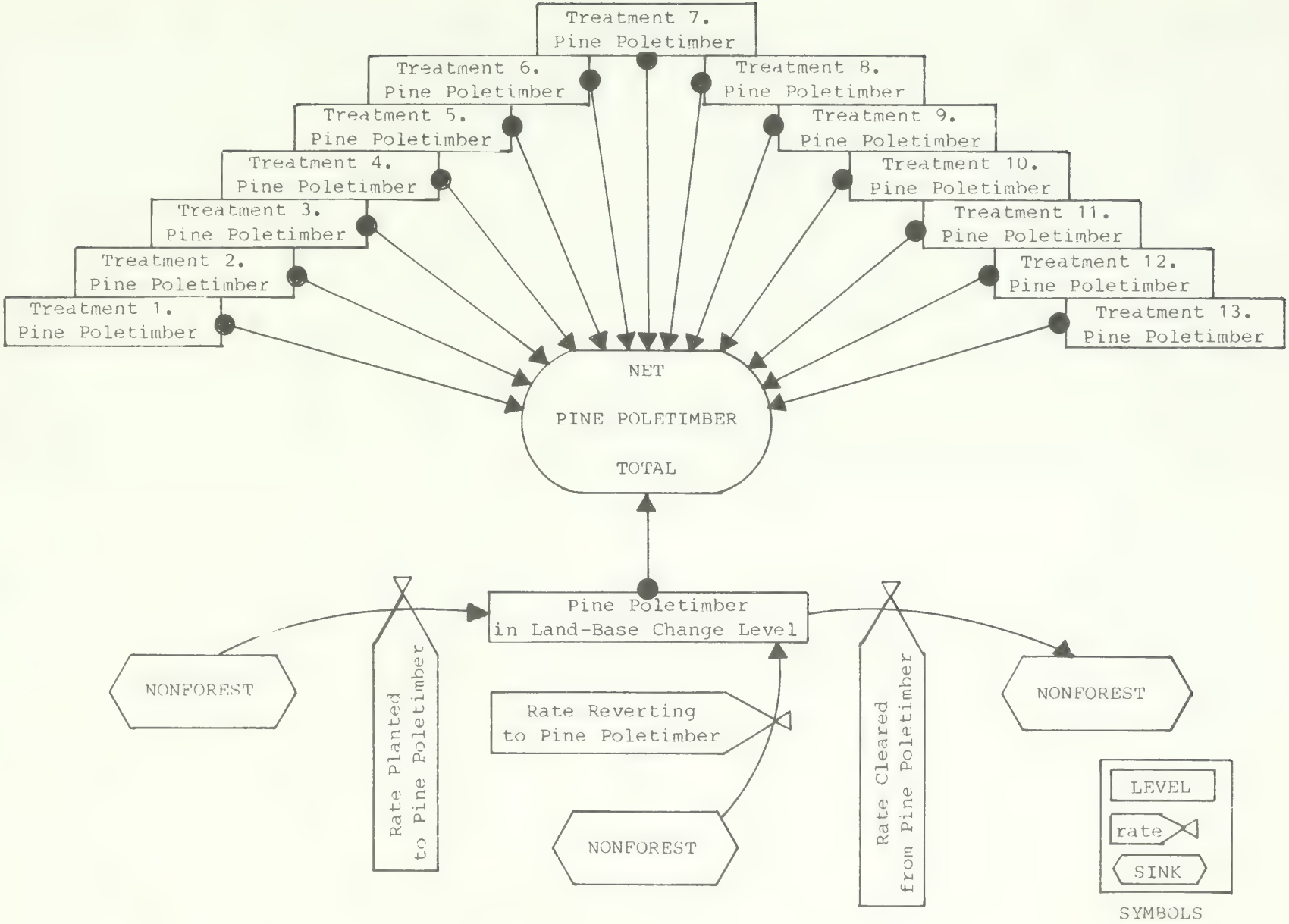

Figure 4.--Flow chart illustrating DYNARIP tabulation of pine poletimber level.

number of nonforest acres planted and reverted, the net pine poletimber acres (and total forest acres) in the regional inventory will diminish accordingly.

Each of the 15 initial forest types and stand sizes are broken down and partialled out to the 13 treatment matrices in exactly the same manner as described above. Each treatment/disturbance matrix is a closed loop that tracks the movement of acreage among the 15 type-size levels enclosed within it. The effect of each treatment or disturbance can thus be isolated. To incorporate assumptions into the model, all the user need do is specify the amount and type of initial acreage rotating through each of the 13 treatment/disturbance matrices. The empirical rates of biological response to treatment then take over and drive the model. The resulting type-size state of regional forest organization is output at the end of each iteration as individual levels are tabulated. Any inventory parameter (such as timber volume) that can be linked to a forest-type/stand-size inventory can be calculated by multiplying the acres in each type-size level by an average factor or stochastic distribution representing that paramenter.

Model Test Run

Since all rates for the Georgia model were developed from the 1972 and 1982 multiresource inventories of the State, one test of model performance is achieved by plugging the 1972 initial inventory into DYNARIP to see how the results compare with what was actually measured in 1982. An obvious advantage, in this case, is that we know what percentages of the 1972 inventory experienced each of the treatments. Although these breakdowns will not be known when the model is projected into the future, such records from the past can be used as a reference upon which to base assumptions about the future.

The results of the model test run are posted in table 1. As should be the case, the differences between the 1982 reported inventory and the 1982 DYNARIP projections are small. Some discrepancy is to be expected because individual plot expansion factors used for the DYNARIP-model input were not calculated in exactly the same manner as they were for the reported inventory. Revision was necessary to make the model more sensitive to individual Survey Units and because lost or added plots could not be used in the calculation of forest-to-forest rates of change. The largest discrepancy between projected and reported 1982 inventory figures is about 8 percent in the pine nonstocked category.

Table 1.--Comparison of 1982 reported Georgia forest inventory and 1982 inventory as projected by DYNARIP using 1972 input data

Forest type-stand size	1982 Reported inventory	1982 DYNARIP inventory projection	Percent difference
	----- Acres -----		Percent
Pine			
Nonstocked	205,658	221,570	+7.7
Seedling	1,232,882	1,235,100	+0.2
Sapling	1,787,115	1,790,500	+.2
Poletimber	3,769,165	3,761,500	-.2
Sawtimber	4,444,099	4,436,200	-.2
Oak-pine			
Nonstocked	37,998	37,035	-2.5
Seedling	458,372	440,160	-4.0
Sapling	476,945	457,980	-4.0
Poletimber	923,878	972,000	+5.2
Sawtimber	1,062,357	1,031,700	-2.9
Hardwood			
Nonstocked	449,893	473,250	+5.2
Seedling	678,457	676,110	-.3
Sapling	1,176,027	1,172,700	-.3
Poletimber	3,028,577	2,971,600	-1.9
Sawtimber	4,002,261	4,055,900	+1.3
Total	23,733,684	23,733,605	--[a]

[a]Negligible.

II. Georgia Pilot Analysis

Before the DYNARIP model could be used to project the 1982 Georgia forest inventory into the future, a problem inherent to the data had to be corrected. The 1972 inventory was slightly confounded by plots straddling more than one condition. For example, if one portion of a plot was in an oak-hickory stand and

the other in a pine stand, the plot may have been typed as oak-pine. Although this practice was eliminated and plots were confined to a single condition in the 1982 survey, its prior use meant that some of the rates of change measured between the two surveys were due to Survey procedural change and not real change. These confounded rates were used in the previous model test run, but cannot be used for future projections. For this reason, 1,900 straddler plots were screened from the data so that pure rates of change could be developed. These pure rates are used in all subsequent DYNARIP runs. The total number of plots supporting the Georgia DYNARIP model was reduced from 6,134 to 4,234.

Regional Response to Individual Treatments/Disturbances

Figures presented in table 2 isolate the potential impact of 11 man-caused and natural disturbances (treatments 2 through 12) on the Georgia forest resource over the next 10 years. The 1982 inventory, which was used as input to the model, is listed in the first column. The 1992 DYNARIP base inventory projection, which assumes that rates of treatment and forest land-base changes will continue at rates observed between 1972 and 1982, is shown in the second column. A complete listing of the base-run output is provided in Appendix B. The remaining columns in table 2 list the output from DYNARIP runs exactly like the base run, except that the effect of one treatment/disturbance at a time was nullified. In other words, the acres which experienced treatments 2, 3, 4, etc., under the base run were relegated to Treatment 1 under each of the null runs. This sequence of runs simulates what the response of the resource would be if one of man's activities or a natural disturbance were completely discontinued and the acres affected by that disturbance were allowed to proceed as they would if totally undisturbed. The potential influence of each treatment or disturbance can be quantified by comparing each of the null runs with the base-run projection and initial (1982) inventory. While the complete cessation of a particular activity may be unrealistic, this exercise demonstrates that analyses of this type can be used to estimate the range of response that can be expected from modifying the amount of acres affected by a particular disruption. As is evident from table 2, harvesting and regeneration practices bear the most potential influence on the future state of forest organization in Georgia. Most of the other treatments and disturbances would not have an overwhelming impact on the regional inventory by the end of 10 years. This means that the instances of these other disturbances are relatively insignificant when viewed in the context of the regional inventory as a whole and/or the resource is highly buffered and reacts to them somewhat slowly.

Georgia Forest Policy Analysis

In addition to isolating the effects of individual disturbances, it is much more meaningful from the standpoint of some forest policy issues to analyze the results of shifting acres from one active treatment to another. If, for instance, a legislative body were interested in changing the composition of a regional inventory, it could use the model to evaluate what is biologically possible within a certain time frame and then to determine what human activities might be modified to best bring about the change. By the same token, if a change in some activity becomes apparent or is anticipated, the model can be used to simulate the prospective results. To show how DYNARIP might be used to satisfy such a role, a forest policy issue of regional significance was chosen for analysis.

For over a decade, much concern has been raised about declining rates of pine regeneration in the South (U.S. Department of Agriculture, Forest Service 1978). Past failure to regenerate harvested pine stands has made future declines of softwood timber supplies in the South almost inevitable (Boyce and Knight 1979). Conspicuously low rates of pine regeneration on lands held by nonindustrial private forest (NIPF) owners have been identified as a major cause of the problem (Knight 1978; National Forest Products Association 1980; Society of American Foresters 1979).

Table 2.--Georgia 1992 projected inventories based on 1972-1982 observed rates of treatment/disturbance, with one treatment/disturbance at a time nullified

Forest type-stand size	1982 Inventory input	1992 Inventory output											
		Base run	Treatment/disturbance nullified										
			2[a]	3[b]	4[c]	5[d]	6[e]	7[f]	8[g]	9[h]	10[i]	11[j]	12[k]
	Thousand acres												
Pine													
Nonstocked	205.7	217.9	227.0	218.1	74.7	218.3	222.5	213.1	218.1	222.9	218.2	218.0	218.2
Seedling	1,232.9	1,215.6	502.9	1,091.0	1,115.8	1,206.8	1,145.0	1,193.1	1,205.7	1,203.4	1,222.3	1,212.5	1,219.2
Sapling	1,787.1	1,858.8	1,509.4	1,819.3	1,843.7	1,857.1	1,649.5	1,814.8	1,861.0	1,872.2	1,935.9	1,852.3	1,861.9
Poletimber	3,769.2	3,029.1	3,219.0	3,142.5	3,178.7	3,034.0	3,053.2	2,982.2	3,009.4	2,974.3	2,917.8	3,068.5	3,038.7
Sawtimber	4,444.1	4,082.3	4,749.7	4,536.8	4,715.7	4,226.1	4,116.2	4,354.3	4,079.8	4,090.6	4,040.5	4,173.3	4,081.9
Oak-Pine													
Nonstocked	38.0	38.0	38.2	38.0	11.3	38.1	39.6	34.7	38.0	38.2	38.1	38.0	38.1
Seedling	458.4	416.1	355.3	266.9	360.5	417.1	420.4	402.3	418.5	391.2	420.6	418.6	418.1
Sapling	476.9	440.5	449.3	373.2	426.3	419.4	453.9	446.2	446.2	447.6	459.4	451.5	447.7
Poletimber	923.9	816.5	847.6	821.5	775.6	798.1	826.4	765.8	828.7	831.6	830.2	777.1	810.2
Sawtimber	1,062.3	940.9	1,001.1	986.3	1,000.3	968.8	950.7	963.9	956.9	945.6	948.3	969.7	938.2
Hardwood													
Nonstocked	449.9	432.5	439.6	435.2	243.8	425.4	469.6	439.0	435.1	416.1	432.8	435.0	439.7
Seedling	678.4	609.5	596.1	393.3	407.9	589.6	611.2	564.9	609.6	579.5	610.3	604.4	610.3
Sapling	1,176.0	1,081.4	1,107.6	967.1	989.1	1,067.3	1,128.1	1,070.7	1,069.7	1,109.2	1,083.2	1,046.3	1,087.4
Poletimber	3,028.6	2,918.1	2,972.6	2,919.6	2,789.6	2,806.5	2,979.8	2,833.1	2,909.2	2,945.2	2,887.9	2,879.5	2,932.2
Sawtimber	4,002.3	4,556.1	4,637.9	4,644.5	4,720.3	4,580.7	4,587.2	4,575.2	4,567.4	4,585.7	4,607.8	4,508.6	4,511.5
Total	23,733.7	22,653.3	22,653.3	22,653.3	22,653.3	22,653.3	22,653.3	22,653.3	22,653.3	22,653.3	22,653.3	22,653.3	22,653.3

[a]Harvest followed by artificial regeneration.
[b]Harvest followed by natural regeneration.
[c]Harvest without regeneration.
[d]Highgrading.
[e]Artificial regeneration on forest land.
[f]Other intermediate cutting.
[g]Commercial thinning.
[h]Prescribed burning.
[i]Disease damage.
[j]Insect damage.
[k]Grazing.

In 1971 the Virginia General Assembly passed the Reforestation of Timberlands Act, designed to increase the rate of pine regeneration on NIPF land in Virginia. The passage of the Federal Forestry Incentives Program (FIP) in 1973 offered the private landowner in Virginia additional stimulus to regenerate more acres to pine. With both programs fully operational by 1975, the average annual acres planted to pine on NIPF land between 1975 and 1981 increased by 131 percent over the average annual acres planted between 1962 and 1971, when no major incentives programs were in effect (U.S. Department of Agriculture, Forest Service 1963-1974, 1974-1980, 1982).

Suppose the Georgia State Legislature were interested in estimating the impact of a bill similar to Virginia's Reforestation of Timberlands Act on Georgia's softwood timber inventory over the next 30 years. The average acres planted annually on NIPF land in Georgia between 1975 and 1981 when FIP was the only major incentives program in effect in Georgia was 25 percent greater than acres planted between 1962 and 1974, when no major programs were in effect. If one assumes that 25 percent of the Virginia increase between 1975 and 1981 was due to the FIP legislation, then one might logically conclude that the other 106 percent of the total increase was likely due to the State bill. This calculation suggests that Georgia might also expect about 100 percent increase in the rate of pine regeneration on NIPF land by enacting legislation similar to Virginia's. This assumption is supported by comparing the rate of NIPF planting in Virginia during the 3 years when only the State bill was in effect (1972-74) with the rates of planting in the State between 1962 and 1971. The comparison indicates the Reforestation Timberlands Act increased planting by 101 percent.

As if the hypothetical Georgia bill were to be passed in 1985 and become operational by 1986, the assumed 100 percent increase in NIPF planting rates was entered into the DYNARIP model to assess the prospective ramifications of the policy change. Between 1972 and 1982, Georgia NIPF owners planted a total of 255,616 acres following a final harvest (treatment 2), 55,690 acres of poorly or nonstocked forest land (treatment 6), and 60,375 acres of nonforest land (land-base change). For the first decade (1982-92), NIPF acres experiencing each of the above three treatments were increased only by 60 percent since the legislation would not become effective until 1986. For the following 2 decades, each was increased by 100 percent. Acres added to treatment 2 were proportionately subtracted from treatments 3 and 4. Acres added to treatment 6 were proportionately subtracted from acres experiencing treatments 1, 10, and 11, hence assuming these acres would otherwise have been left to nature. Additional acres of planted nonforest were treated as a direct increase to the forest land base. Prospective results of the policy change on the pine resource of Georgia are presented in column 2 of table 3. A measure of the impact of the policy change can be obtained by comparing the policy-change-run with the base-run projection.

By the end of the first decade, pine nonstocked and pine seedling stands are perceptibly impacted. Nonstocked acreage declines and pine seedling stands

Table 3.--Comparison of DYNARIP pine acreage base-run projection, and projected pine acreage resulting from hypothetical policy change, Georgia, 1992-2012

Year/pine stand sizes	Base-run projection	Policy change projection	Percent difference
	- - Thousand acres - -		Percent
1982:			
Nonstocked	217.9	206.6	-5.2
Seedling	1,215.6	1,316.2	+8.3
Sapling	1,858.8	1,930.9	+3.9
Poletimber	3,029.1	3,024.4	-.2
Sawtimber	4,082.3	4,071.0	-.3
Total	10,403.7	10,549.1	+1.4
2002:			
Nonstocked	203.5	185.7	-8.7
Seedling	1,099.3	1,256.4	+14.3
Sapling	1,755.9	1,897.1	+8.0
Poletimber	2,792.5	2,859.8	+2.4
Sawtimber	3,612.4	3,602.9	-.3
Total	9,463.6	9,801.9	+3.6
2012:			
Nonstocked	185.7	170.6	-8.1
Seedling	1,003.8	1,159.2	+15.5
Sapling	1,609.4	1,768.8	+9.9
Poletimber	2,567.8	2,716.0	+5.8
Sawtimber	3,236.5	3,262.9	+.8
Total	8,603.2	9,077.5	+5.5

increase. These trends continue throughout the 30-year simulation. Also by 1992, some of the increased pine regeneration is beginning to boost the area of pine saplings. Pine poletimber and sawtimber stands remain largely unaffected, except for slight reductions due to the liquidation of some poorly stocked and marginally productive stands.

By the year 2002, the effect of the policy change on pine saplings becomes apparent as the acres in this category are increased by about 8 percent over what would be present without the legislation. Some of the stands planted early under the imaginary program are now starting to reach poletimber size. Pine sawtimber still remains relatively unchanged.

By 2012, pine poletimber acreage is expanded by 6 percent. The program is just starting to influence pine sawtimber. If our assumptions are reasonably accurate, the hypothetical bill would increase the total area of pine by about 0.5 million acres at the end of 30 years. However, even with legislation such as this in effect, the DYNARIP simulation indicates the total pine acreage would still decline by about 2.4 million acres from what was measured in 1982.

To further quantify the effects of the policy change, average standing volume factors were developed and added to the core model. From the 1982 inventory, the average standing growing-stock cubic-foot volume per acre by softwood and hardwood, by sawtimber and poletimber was calculated for each of the 15 forest-type/stand-size combinations. These factors were then multiplied by the acreage in each of the type-size levels to simulate the Georgia growing-stock inventory. The DYNARIP 30-year softwood volume projection output is presented in table 4.

If the stated assumptions become reality, and there are no substantial reductions of softwood removals, increased planting now would not significantly increase softwood volume in the State for at least 20 years. Most of the additional planted acres would not reach poletimber size until they were at least 15 years of age. By the end of 30 years, the softwood growing-stock inventory volume under the program of increased NIPF planting could be increased by about 200 million cubic feet over the prospective volume if no legislation is enacted. Even so, this still represents a 3.6 billion cubic-foot decline from the present softwood growing-stock inventory.

The relatively meager potential increase in the 30-year softwood volume inventory indicated by the policy-change projection stems from three main factors:

1. The most notable factor is the present low rate of artificial regeneration on NIPF land. NIPF owners planted only 22 percent of the total stands planted in Georgia between 1972 and 1982. However, they harvested 61 percent of all pine stands harvested during this same period. Even if they doubled their rate of planting, this would still leave 62 percent of their harvested pine stands unplanted. In contrast, forest industry artificially regenerated about the equivalent of what pine stands they harvested. In order to substantially increase the softwood standing inventory volume, NIPF planting rates would have to be more than doubled.

2. Some of the additional acres of pine planted under the hypothetical program would have regenerated naturally to pine anyway. Also, some of the additional pine plantations would be unsuccessful.

3. The entire benefit of the policy change is not represented by the inven-

Table 4.--Comparison of DYNARIP softwood growing-stock inventory volume base-run projection, and projected softwood volume resulting from hypothetical policy change, Georgia, 1992-2012

Year/softwood timber size	Base-run projection	Policy-change projection	Percent difference
	Billion cubic feet		Percent
1992:			
Poletimber	4.241	4.24[a]	--
Sawtimber	10.291	10.269	-0.2
Total	14.532	14.511	-.1
2002:			
Poletimber	3.892	3.950	+1.5
Sawtimber	9.425	9.420	-.1
Total	13.317	13.370	+.4
2012:			
Poletimber	3.579	3.704	+3.5
Sawtimber	8.693	8.762	+.8
Total	12.272	12.466	+1.6

[a]Negligible.

tory figures in table 4 because extra volume is also being put on the market due to the early liquidation of some poorly stocked stands, as well as extra volume generated by the planting program. This additional volume put on the market could make the program look more attractive.

Although beyond the scope of this paper, the hypothetical Georgia policy-change analysis could be carried further. Average growing-stock removals per acre by forest type, stand size, and treatment could be developed to gain a measure of softwood growing-stock volume put on the market over the projection period. With this additional information, analysts would have much of the input necessary for a detailed economic analysis of the hypothetical legislation. Algorithms tracking wildlife habitat, recreation value, esthetics, shifts of forest ownership, etc., could also be added to the core model to follow prospective trends in these areas of concern.

As can be gleaned from the above analysis, the trends mapped by the DYNARIP model reinforce what common sense would reveal to the regional analyst if events take place as described. The value of the DYNARIP model results from its ability to quantify these perceptions of the future and to highlight any unexpected consequences resulting from a proposed course of action.

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Appendix A.

DYNARIP Model Listing

The DYNARIP core model used for the Georgia 1982-1992 base-run projection is listed below. The output from the program as listed here is provided in Appendix B.

This program will run on a DYNAMO/370 mainframe compiler. The mainframe compiler is capable of handling up to 13 separate treatments/disturbances with adequate storage capacity for most algorithms that might be added to the core model. DYNARIP runs should generally cost less than $5.

Program Listing

```
00010 *  GEORGIA DYNARIP,OUTPUT SCALED
00020 NOTE  <<<<<<<<<< FOREST TO FOREST SECTOR >>>>>>>>>>
00030 NOTE
00040 NOTE  RATE TRANSFERRED TO A TYPE
00050 NOTE
00060 MACRO  RTOTYP(FRTP1,FRTP2,FRTP3,FRTP4,FRTP5,FRTP6,FRTP7,FRTP8,FRTP9,
00070 X  FRTP10,FRTP11,FRTP12,FRTP13,FRTP14,FFBT1,FFBT2,FFBT3,FFBT4,FFBT5,
00080 X  FFBT6,FFBT7,FFBT8,FFBT9,FFBT10,FFBT11,FFBT12,FFBT13,FFBT14)
00090 R  RTOTYP.KL=
00100 X  (FRTP1*FFBT1/REMEAS)+
00110 X  (FRTP2*FFBT2/REMEAS)+
00120 X  (FRTP3*FFBT3/REMEAS)+
00130 X  (FRTP4*FFBT4/REMEAS)+
00140 X  (FRTP5*FFBT5/REMEAS)+
00150 X  (FRTP6*FFBT6/REMEAS)+
00160 X  (FRTP7*FFBT7/REMEAS)+
00170 X  (FRTP8*FFBT8/REMEAS)+
00180 X  (FRTP9*FFBT9/REMEAS)+
00190 X  (FRTP10*FFBT10/REMEAS)+
00200 X  (FRTP11*FFBT11/REMEAS)+
00210 X  (FRTP12*FFBT12/REMEAS)+
00220 X  (FRTP13*FFBT13/REMEAS)+
00230 X  (FRTP14*FFBT14/REMEAS)
```

```
00240 MEND
00250 NOTE
00260 NOTE  AREA AT TIME K BY SIZE/TYPE AND TREATMENT
00270 NOTE
00280 MACRO  TYPBTR(INTYP,CLE,PERTR,TOTP1,TOTP2,TOTP3,TOTP4,TOTP5,TOTP6,
00290 X  TOTP7,TOTP8,TOTP9,TOTP10,TOTP11,TOTP12,TOTP13,TOTP14,D1,D2,D3,D4,D5,
00300 X  D6,D7,D8,D9,D10,D11,D12,D13,D14,DD1,DD2,DD3,DD4,DD5,DD6,DD7,DD8,DD9,
00310 X  DD10,DD11,DD12,DD13,DD14,FFBT)
00320 L  TYPBTR.K=TYPBTR.J+DT*($TOTYP.JK-$FRTYP.JK)
00330 N  TYPBTR=(INTYP-(CLE*TACA*REMEAS))*PERTR
00340 N  FFBT=TYPBTR
00350 R  $FRTYP.KL=$RFRTYP*FFBT/REMEAS
00360 N  $RFRTYP=TOTP1+TOTP2+TOTP3+TOTP4+TOTP5+TOTP6+TOTP7+TOTP8+TOTP9+
00370 X  TOTP10+TOTP11+TOTP12+TOTP13+TOTP14
00380 R  $TOTYP.KL=RTOTYP(D1,D2,D3,D4,D5,D6,D7,D8,D9,D10,D11,D12,D13,D14,
00390 X  DD1,DD2,DD3,DD4,DD5,DD6,DD7,DD8,DD9,DD10,DD11,DD12,DD13,DD14)
00400 MEND
00410 NOTE
00420 NOTE  TREATMENT 1.
00430 NOTE
00440 NOTE  PINE NONSTOCKED
00450 A  PA1.K=TYPBTR(IPA,CPA,PATD1,PAPB1,PAPC1,PAPD1,PAPE1,PAOA1,
00460 X  PAOB1,PAOC1,PAOD1,PAOE1,PAHA1,PAHB1,PAHC1,PAHD1,PAHE1,
00470 X  PBPA1,PCPA1,PDPA1,PEPA1,OAPA1,OBPA1,OCPA1,ODPA1,OEPA1,
00480 X  HAPA1,HBPA1,HCPA1,HDPA1,HEPA1,FFPB1,FFPC1,FFPD1,FFPE1,
00490 X  FFOA1,FFOB1,FFOC1,FFOD1,FFOE1,FFHA1,FFHB1,FFHC1,
00500 X  FFHD1,FFHE1,FFPA1)
00510 NOTE  PINE SEEDLING
00520 A  PB1.K=TYPBTR(IPB,CPB,PBTD1,PBPA1,PBPC1,PBPD1,PBPE1,PBOA1,
00530 X  PBOB1,PBOC1,PBOD1,PBOE1,PBHA1,PBHB1,PBHC1,PBHD1,PBHE1,
00540 X  PAPB1,PCPB1,PDPB1,PEPB1,OAPB1,OBPB1,OCPB1,ODPB1,OEPB1,
00550 X  HAPB1,HBPB1,HCPB1,HDPB1,HEPB1,FFPA1,FFPC1,FFPD1,FFPE1,
00560 X  FFOA1,FFOB1,FFOC1,FFOD1,FFOE1,FFHA1,FFHB1,FFHC1,
00570 X  FFHD1,FFHE1,FFPB1)
00580 NOTE  PINE SAPLING
00590 A  PC1.K=TYPBTR(IPC,CPC,PCTD1,PCPB1,PCPA1,PCPD1,PCPE1,PCOA1,
00600 X  PCOB1,PCOC1,PCOD1,PCOE1,PCHA1,PCHB1,PCHC1,PCHD1,PCHE1,
00610 X  PBPC1,PAPC1,PDPC1,PEPC1,OAPC1,OBPC1,OCPC1,ODPC1,OEPC1,
00620 X  HAPC1,HBPC1,HCPC1,HDPC1,HEPC1,FFPB1,FFPA1,FFPD1,FFPE1,
00630 X  FFOA1,FFOB1,FFOC1,FFOD1,FFOE1,FFHA1,FFHB1,FFHC1,
00640 X  FFHD1,FFHE1,FFPC1)
00650 NOTE  PINE POLETIMBER
00660 A  PD1.K=TYPBTR(IPD,CPD,PDTD1,PDPB1,PDPC1,PDPA1,PDPE1,PDOA1,
00670 X  PDOB1,PDOC1,PDOD1,PDOE1,PDHA1,PDHB1,PDHC1,PDHD1,PDHE1,
00680 X  PBPD1,PCPD1,PAPD1,PEPD1,OAPD1,OBPD1,OCPD1,ODPD1,OEPD1,
00690 X  HAPD1,HBPD1,HCPD1,HDPD1,HEPD1,FFPB1,FFPC1,FFPA1,FFPE1,
00700 X  FFOA1,FFOB1,FFOC1,FFOD1,FFOE1,FFHA1,FFHB1,FFHC1,
00710 X  FFHD1,FFHE1,FFPD1)
00720 NOTE  PINE SAWTIMBER
00730 A  PE1.K=TYPBTR(IPE,CPE,PETD1,PEPB1,PEPC1,PEPD1,PEPA1,PEOA1,
00740 X  PEOB1,PEOC1,PEOD1,PEOE1,PEHA1,PEHB1,PEHC1,PEHD1,PEHE1,
00750 X  PBPE1,PCPE1,PDPE1,PAPE1,OAPE1,OBPE1,OCPE1,ODPE1,OEPE1,
00760 X  HAPE1,HBPE1,HCPE1,HDPE1,HEPE1,FFPB1,FFPC1,FFPD1,FFPA1,
00770 X  FFOA1,FFOB1,FFOC1,FFOD1,FFOE1,FFHA1,FFHB1,FFHC1,
00780 X  FFHD1,FFHE1,FFPE1)
00790 NOTE  OAK-PINE NONSTOCKED
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```
00800 A  OA1.K=TYPBTR(IOA,COA,OATD1,OAPB1,OAPC1,OAPD1,OAPE1,OAPA1,
00810 X  OAOB1,OAOC1,OAOD1,OAOE1,OAHA1,OAHB1,OAHC1,OAHD1,OAHE1,
00820 X  PBOA1,PCOA1,PDOA1,PEOA1,PAOA1,OBOA1,OCOA1,ODOA1,OEOA1,
00830 X  HAOA1,HBOA1,HCOA1,HDOA1,HEOA1,FFPB1,FFPC1,FFPD1,FFPE1,
00840 X  FFPA1,FFOB1,FFOC1,FFOD1,FFOE1,FFHA1,FFHB1,FFHC1,
00850 X  FFHD1,FFHE1,FFOA1)
00860 NOTE  OAK-PINE SEEDLING
00870 A  OB1.K=TYPBTR(IOB,COB,OBTD1,OBPB1,OBPC1,OBPD1,OBPE1,OBOA1,
00880 X  OBPA1,OBOC1,OBOD1,OBOE1,OBHA1,OBHB1,OBHC1,OBHD1,OBHE1,
00890 X  PBOB1,PCOB1,PDOB1,PEOB1,OAOB1,PAOB1,OCOB1,ODOB1,OEOB1,
00900 X  HAOB1,HBOB1,HCOB1,HDOB1,HEOB1,FFPB1,FFPC1,FFPD1,FFPE1,
00910 X  FFOA1,FFPA1,FFOC1,FFOD1,FFOE1,FFHA1,FFHB1,FFHC1,
00920 X  FFHD1,FFHE1,FFOB1)
00930 NOTE  OAK-PINE SAPLING
00940 A  OC1.K=TYPBTR(IOC,COC,OCTD1,OCPB1,OCPC1,OCPD1,OCPE1,OCOA1,
00950 X  OCOB1,OCPA1,OCOD1,OCOE1,OCHA1,OCHB1,OCHC1,OCHD1,OCHE1,
00960 X  PBOC1,PCOC1,PDOC1,PEOC1,OAOC1,OBOC1,PAOC1,ODOC1,OEOC1,
00970 X  HAOC1,HBOC1,HCOC1,HDOC1,HEOC1,FFPB1,FFPC1,FFPD1,FFPE1,
00980 X  FFOA1,FFOB1,FFPA1,FFOD1,FFOE1,FFHA1,FFHB1,FFHC1,
00990 X  FFHD1,FFHE1,FFOC1)
01000 NOTE  OAK-PINE POLETIMBER
01010 A  OD1.K=TYPBTR(IOD,COD,ODTD1,ODPB1,ODPC1,ODPD1,ODPE1,ODOA1,
01020 X  ODOB1,ODOC1,ODPA1,ODOE1,ODHA1,ODHB1,ODHC1,ODHD1,ODHE1,
01030 X  PBOD1,PCOD1,PDOD1,PEOD1,OAOD1,OBOD1,OCOD1,PAOD1,OEOD1,
01040 X  HAOD1,HBOD1,HCOD1,HDOD1,HEOD1,FFPB1,FFPC1,FFPD1,FFPE1,
01050 X  FFOA1,FFOB1,FFOC1,FFPA1,FFOE1,FFHA1,FFHB1,FFHC1,
01060 X  FFHD1,FFHE1,FFOD1)
01070 NOTE  OAK-PINE SAWTIMBER
01080 A  OE1.K=TYPBTR(IOE,COE,OETD1,OEPB1,OEPC1,OEPD1,OEPE1,OEOA1,
01090 X  OEOB1,OEOC1,OEOD1,OEPA1,OEHA1,OEHB1,OEHC1,OEHD1,OEHE1,
01100 X  PBOE1,PCOE1,PDOE1,PEOE1,OAOE1,OBOE1,OCOE1,ODOE1,PAOE1,
01110 X  HAOE1,HBOE1,HCOE1,HDOE1,HEOE1,FFPB1,FFPC1,FFPD1,FFPE1,
01120 X  FFOA1,FFOB1,FFOC1,FFOD1,FFPA1,FFHA1,FFHB1,FFHC1,
01130 X  FFHD1,FFHE1,FFOE1)
01140 NOTE  HARDWOOD NONSTOCKED
01150 A  HA1.K=TYPBTR(IHA,CHA,HATD1,HAPB1,HAPC1,HAPD1,HAPE1,HAOA1,
01160 X  HAOB1,HAOC1,HAOD1,HAOE1,HAPA1,HAHB1,HAHC1,HAHD1,HAHE1,
01170 X  PBHA1,PCHA1,PDHA1,PEHA1,OAHA1,OBHA1,OCHA1,ODHA1,OEHA1,
01180 X  PAHA1,HBHA1,HCHA1,HDHA1,HEHA1,FFPB1,FFPC1,FFPD1,FFPE1,
01190 X  FFOA1,FFOB1,FFOC1,FFOD1,FFOE1,FFPA1,FFHB1,FFHC1,
01200 X  FFHD1,FFHE1,FFHA1)
01210 NOTE  HARDWOOD SEEDLING
01220 A  HB1.K=TYPBTR(IHB,CHB,HBTD1,HBPB1,HBPC1,HBPD1,HBPE1,HBOA1,
01230 X  HBOB1,HBOC1,HBOD1,HBOE1,HBHA1,HBPA1,HBHC1,HBHD1,HBHE1,
01240 X  PBHB1,PCHB1,PDHB1,PEHB1,OAHB1,OBHB1,OCHB1,ODHB1,OEHB1,
01250 X  HAHB1,PAHB1,HCHB1,HDHB1,HEHB1,FFPB1,FFPC1,FFPD1,FFPE1,
01260 X  FFOA1,FFOB1,FFOC1,FFOD1,FFOE1,FFHA1,FFPA1,FFHC1,
01270 X  FFHD1,FFHE1,FFHB1)
01280 NOTE  HARDWOOD SAPLING
01290 A  HC1.K=TYPBTR(IHC,CHC,HCTD1,HCPB1,HCPC1,HCPD1,HCPE1,HCOA1,
01300 X  HCOB1,HCOC1,HCOD1,HCOE1,HCHA1,HCHB1,HCPA1,HCHD1,HCHE1,
01310 X  PBHC1,PCHC1,PDHC1,PEHC1,OAHC1,OBHC1,OCHC1,ODHC1,OEHC1,
01320 X  HAHC1,HBHC1,PAHC1,HDHC1,HEHC1,FFPB1,FFPC1,FFPD1,FFPE1,
01330 X  FFOA1,FFOB1,FFOC1,FFOD1,FFOE1,FFHA1,FFHB1,FFPA1,
01340 X  FFHD1,FFHE1,FFHC1)
01350 NOTE  HARDWOOD POLETIMBER
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01360 A  HD1.K=TYPBTR(IHD,CHD,HDTD1,HDPB1,HDPC1,HDPD1,HDPE1,HDOA1,
01370 X  HDOB1,HDOC1,HDOD1,HDOE1,HDHA1,HDHB1,HDHC1,HDPA1,HDHE1,
01380 X  PBHD1,PCHD1,PDHD1,PEHD1,OAHD1,OBHD1,OCHD1,ODHD1,OEHD1,
01390 X  HAHD1,HBHD1,HCHD1,PAHD1,HEHD1,FFPB1,FFPC1,FFPD1,FFPE1,
01400 X  FFOA1,FFOB1,FFOC1,FFOD1,FFOE1,FFHA1,FFHB1,FFHC1,
01410 X  FFPA1,FFHE1,FFHD1)
01420 NOTE  HARDWOOD SAWTIMBER
01430 A  HE1.K=TYPBTR(IHE,CHE,HETD1,HEPB1,HEPC1,HEPD1,HEPE1,HEOA1,
01440 X  HEOB1,HEOC1,HEOD1,HEOE1,HEHA1,HEHB1,HEHC1,HEHD1,HEPA1,
01450 X  PBHE1,PCHE1,PDHE1,PEHE1,OAHE1,OBHE1,OCHE1,ODHE1,OEHE1,
01460 X  HAHE1,HBHE1,HCHE1,HDHE1,PAHE1,FFPB1,FFPC1,FFPD1,FFPE1,
01470 X  FFOA1,FFOB1,FFOC1,FFOD1,FFOE1,FFHA1,FFHB1,FFHC1,
01480 X  FFHD1,FFPA1,FFHE1)
01490 NOTE
01500 NOTE
01510 NOTE
01520 NOTE  TREATMENTS 2-13 OMITTED
01530 NOTE
01540 NOTE
01550 NOTE
01560 NOTE  <<<<<<<<<< FOREST LANDBASE CHANGE SECTOR >>>>>>>>>>
01570 NOTE
01580 L  NLBCPA.K=(NLBCPA.J+DT*RLBCPA.JK)
01590 N  NLBCPA=CPA*TACA*REMEAS
01600 R  RLBCPA.KL=(PPA*TAPA)+(RPA*TARA)-(CPA*TACA)
01610 L  NLBCPB.K=(NLBCPB.J+DT*RLBCPB.JK)
01620 N  NLBCPB=CPB*TACA*REMEAS
01630 R  RLBCPB.KL=(PPB*TAPA)+(RPB*TARA)-(CPB*TACA)
01640 L  NLBCPC.K=(NLBCPC.J+DT*RLBCPC.JK)
01650 N  NLBCPC=CPC*TACA*REMEAS
01660 R  RLBCPC.KL=(PPC*TAPA)+(RPC*TARA)-(CPC*TACA)
01670 L  NLBCPD.K=(NLBCPD.J+DT*RLBCPD.JK)
01680 N  NLBCPD=CPD*TACA*REMEAS
01690 R  RLBCPD.KL=(PPD*TAPA)+(RPD*TARA)-(CPD*TACA)
01700 L  NLBCPE.K=(NLBCPE.J+DT*RLBCPE.JK)
01710 N  NLBCPE=CPE*TACA*REMEAS
01720 R  RLBCPE.KL=(PPE*TAPA)+(RPE*TARA)-(CPE*TACA)
01730 L  NLBCOA.K=(NLBCOA.J+DT*RLBCOA.JK)
01740 N  NLBCOA=COA*TACA*REMEAS
01750 R  RLBCOA.KL=(POA*TAPA)+(ROA*TARA)-(COA*TACA)
01760 L  NLBCOB.K=(NLBCOB.J+DT*RLBCOB.JK)
01770 N  NLBCOB=COB*TACA*REMEAS
01780 R  RLBCOB.KL=(POB*TAPA)+(ROB*TARA)-(COB*TACA)
01790 L  NLBCOC.K=(NLBCOC.J+DT*RLBCOC.JK)
01800 N  NLBCOC=COC*TACA*REMEAS
01810 R  RLBCOC.KL=(POC*TAPA)+(ROC*TARA)-(COC*TACA)
01820 L  NLBCOD.K=(NLBCOD.J+DT*RLBCOD.JK)
01830 N  NLBCOD=COD*TACA*REMEAS
01840 R  RLBCOD.KL=(POD*TAPA)+(ROD*TARA)-(COD*TACA)
01850 L  NLBCOE.K=(NLBCOE.J+DT*RLBCOE.JK)
01860 N  NLBCOE=COE*TACA*REMEAS
01870 R  RLBCOE.KL=(POE*TAPA)+(ROE*TARA)-(COE*TACA)
01880 L  NLBCHA.K=(NLBCHA.J+DT*RLBCHA.JK)
01890 N  NLBCHA=CHA*TACA*REMEAS
01900 R  RLBCHA.KL=(PHA*TAPA)+(RHA*TARA)-(CHA*TACA)
01910 L  NLBCHB.K=(NLBCHB.J+DT*RLBCHB.JK)
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01920 N  NLBCHB=CHB*TACA*REMEAS
01930 R  RLBCHB.KL=(PHB*TAPA)+(RHB*TARA)-(CHB*TACA)
01940 L  NLBCHC.K=(NLBCHC.J+DT*RLBCHC.JK)
01950 N  NLBCHC=CHC*TACA*REMEAS
01960 R  RLBCHC.KL=(PHC*TAPA)+(RHC*TARA)-(CHC*TACA)
01970 L  NLBCHD.K=(NLBCHD.J+DT*RLBCHD.JK)
01980 N  NLBCHD=CHD*TACA*REMEAS
01990 R  RLBCHD.KL=(PHD*TAPA)+(RHD*TARA)-(CHD*TACA)
02000 L  NLBCHE.K=(NLBCHE.J+DT*RLBCHE.JK)
02010 N  NLBCHE=CHE*TACA*REMEAS
02020 R  RLBCHE.KL=(PHE*TAPA)+(RHE*TARA)-(CHE*TACA)
02030 NOTE
02040 NOTE  <<<<<<<<<< SUMMATION OF TYPE-SIZES FOR OUTPUT >>>>>>>>>>
02050 NOTE
02060 A  PA.K=MAX((PA1.K+PA2.K+PA3.K+PA4.K+PA5.K+PA6.K+PA7.K+PA8.K+PA9.K+PA10.
02070 X  K+PA11.K+PA12.K+PA13.K+NLBCPA.K),0)
02080 A  PB.K=MAX((PB1.K+PB2.K+PB3.K+PB4.K+PB5.K+PB6.K+PB7.K+PB8.K+PB9.K+PB10.
02090 X  K+PB11.K+PB12.K+PB13.K+NLBCPB.K),0)
02100 A  PC.K=MAX((PC1.K+PC2.K+PC3.K+PC4.K+PC5.K+PC6.K+PC7.K+PC8.K+PC9.K+PC10.
02110 X  K+PC11.K+PC12.K+PC13.K+NLBCPC.K),0)
02120 A  PD.K=MAX((PD1.K+PD2.K+PD3.K+PD4.K+PD5.K+PD6.K+PD7.K+PD8.K+PD9.K+PD10.
02130 X  K+PD11.K+PD12.K+PD13.K+NLBCPD.K),0)
02140 A  PE.K=MAX((PE1.K+PE2.K+PE3.K+PE4.K+PE5.K+PE6.K+PE7.K+PE8.K+PE9.K+PE10.
02150 X  K+PE11.K+PE12.K+PE13.K+NLBCPE.K),0)
02160 A  OA.K=MAX((OA1.K+OA2.K+OA3.K+OA4.K+OA5.K+OA6.K+OA7.K+OA8.K+OA9.K+OA10.
02170 X  K+OA11.K+OA12.K+OA13.K+NLBCOA.K),0)
02180 A  OB.K=MAX((OB1.K+OB2.K+OB3.K+OB4.K+OB5.K+OB6.K+OB7.K+OB8.K+OB9.K+OB10.
02190 X  K+OB11.K+OB12.K+OB13.K+NLBCOB.K),0)
02200 A  OC.K=MAX((OC1.K+OC2.K+OC3.K+OC4.K+OC5.K+OC6.K+OC7.K+OC8.K+OC9.K+OC10.
02210 X  K+OC11.K+OC12.K+OC13.K+NLBCOC.K),0)
02220 A  OD.K=MAX((OD1.K+OD2.K+OD3.K+OD4.K+OD5.K+OD6.K+OD7.K+OD8.K+OD9.K+OD10.
02230 X  K+OD11.K+OD12.K+OD13.K+NLBCOD.K),0)
02240 A  OE.K=MAX((OE1.K+OE2.K+OE3.K+OE4.K+OE5.K+OE6.K+OE7.K+OE8.K+OE9.K+OE10.
02250 X  K+OE11.K+OE12.K+OE13.K+NLBCOE.K),0)
02260 A  HA.K=MAX((HA1.K+HA2.K+HA3.K+HA4.K+HA5.K+HA6.K+HA7.K+HA8.K+HA9.K+HA10.
02270 X  K+HA11.K+HA12.K+HA13.K+NLBCHA.K),0)
02280 A  HB.K=MAX((HB1.K+HB2.K+HB3.K+HB4.K+HB5.K+HB6.K+HB7.K+HB8.K+HB9.K+HB10.
02290 X  K+HB11.K+HB12.K+HB13.K+NLBCHB.K),0)
02300 A  HC.K=MAX((HC1.K+HC2.K+HC3.K+HC4.K+HC5.K+HC6.K+HC7.K+HC8.K+HC9.K+HC10.
02310 X  K+HC11.K+HC12.K+HC13.K+NLBCHC.K),0)
02320 A  HD.K=MAX((HD1.K+HD2.K+HD3.K+HD4.K+HD5.K+HD6.K+HD7.K+HD8.K+HD9.K+HD10.
02330 X  K+HD11.K+HD12.K+HD13.K+NLBCHD.K),0)
02340 A  HE.K=MAX((HE1.K+HE2.K+HE3.K+HE4.K+HE5.K+HE6.K+HE7.K+HE8.K+HE9.K+HE10.
02350 X  K+HE11.K+HE12.K+HE13.K+NLBCHE.K),0)
02360 A  P.K=PA.K+PB.K+PC.K+PD.K+PE.K
02370 A  O.K=OA.K+OB.K+OC.K+OD.K+OE.K
02380 A  H.K=HA.K+HB.K+HC.K+HD.K+HE.K
02390 A  T.K=P.K+O.K+H.K
02400 A  A.K=PA.K+OA.K+HA.K
02410 A  B.K=PB.K+OB.K+HB.K
02420 A  C.K=PC.K+OC.K+HC.K
02430 A  D.K=PD.K+OD.K+HD.K
02440 A  E.K=PE.K+OE.K+HE.K
02450 A  PERA.K=(A.K/T.K)*100
02460 A  PERB.K=(B.K/T.K)*100
02470 A  PERC.K=(C.K/T.K)*100
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02480 A  PERD.K=(D.K/T.K)*100
02490 A  PERE.K=(E.K/T.K)*100
02500 A  PERP.K=(P.K/T.K)*100
02510 A  PERO.K=(O.K/T.K)*100
02520 A  PERH.K=(H.K/T.K)*100
02530 A  PERPA.K=(PA.K/T.K)*100
02540 A  PERPB.K=(PB.K/T.K)*100
02550 A  PERPC.K=(PC.K/T.K)*100
02560 A  PERPD.K=(PD.K/T.K)*100
02570 A  PERPE.K=(PE.K/T.K)*100
02580 A  PEROA.K=(OA.K/T.K)*100
02590 A  PEROB.K=(OB.K/T.K)*100
02600 A  PEROC.K=(OC.K/T.K)*100
02610 A  PEROD.K=(OD.K/T.K)*100
02620 A  PEROE.K=(OE.K/T.K)*100
02630 A  PERHA.K=(HA.K/T.K)*100
02640 A  PERHB.K=(HB.K/T.K)*100
02650 A  PERHC.K=(HC.K/T.K)*100
02660 A  PERHD.K=(HD.K/T.K)*100
02670 A  PERHE.K=(HE.K/T.K)*100
02680 NOTE
02690 NOTE  <<<<<<<<<< EQUATIONS TO STOP RUN IF LEVEL FALLS BELOW 0 >>>>>>>>>>
02700 NOTE
02710 A  STOPPA.K=1/PA.K
02720 A  STOPPB.K=1/PB.K
02730 A  STOPPC.K=1/PC.K
02740 A  STOPPD.K=1/PD.K
02750 A  STOPPE.K=1/PE.K
02760 A  STOPOA.K=1/OA.K
02770 A  STOPOB.K=1/OB.K
02780 A  STOPOC.K=1/OC.K
02790 A  STOPOD.K=1/OD.K
02800 A  STOPOE.K=1/OE.K
02810 A  STOPHA.K=1/HA.K
02820 A  STOPHB.K=1/HB.K
02830 A  STOPHC.K=1/HC.K
02840 A  STOPHD.K=1/HD.K
02850 A  STOPHE.K=1/HE.K
02860 NOTE
02870 NOTE  <<<<<<<< SUMMATION OF STANDING MERCH. CU. VOL. (CU. FT.) >>>>>>>>>
02880 NOTE
02890 A  TSSV.K=PASSV.K+PBSSV.K+PCSSV.K+PDSSV.K+PESSV.K+OASSV.K+OBSSV.K+
02900 X  OCSSV.K+ODSSV.K+OESSV.K+HASSV.K+HBSSV.K+HCSSV.K+HDSSV.K+HESSV.K
02910 A  THSV.K=PAHSV.K+PBHSV.K+PCHSV.K+PDHSV.K+PEHSV.K+OAHSV.K+OBHSV.K+
02920 X  OCHSV.K+ODHSV.K+OEHSV.K+HAHSV.K+HBHSV.K+HCHSV.K+HDHSV.K+HEHSV.K
02930 A  TSPV.K=PASPV.K+PBSPV.K+PCSPV.K+PDSPV.K+PESPV.K+OASPV.K+OBSPV.K+
02940 X  OCSPV.K+ODSPV.K+OESPV.K+HASPV.K+HBSPV.K+HCSPV.K+HDSPV.K+HESPV.K
02950 A  THPV.K=PAHPV.K+PBHPV.K+PCHPV.K+PDHPV.K+PEHPV.K+OAHPV.K+OBHPV.K+
02960 X  OCHPV.K+ODHPV.K+OEHPV.K+HAHPV.K+HBHPV.K+HCHPV.K+HDHPV.K+HEHPV.K
02970 A  TV.K=TSSV.K+THSV.K+TSPV.K+THPV.K
02980 NOTE
02990 NOTE  <<<<<<<<<< MODEL CONTROLS >>>>>>>>>>
03000 NOTE
03010 SPEC  DT=.25/PRTPER=1/PLTPER=.2
03020 N     LENGTH=MIN(10,REMEAS)
03030 PRINT  PA,OA,HA,A,(0,1)PERA,PERPA,PEROA,PERHA,TSSV(9,3)
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03040 PRINT  PB,OB,HB,B,(0,1)PERB,PERPB,PEROB,PERHB,THSV(9,3)
03050 PRINT  PC,OC,HC,C,(0,1)PERC,PERPC,PEROC,PERHC,TSPV(9,3)
03060 PRINT  PD,OD,HD,D,(0,1)PERD,PERPD,PEROD,PERHD,THPV(9,3)
03070 PRINT  PE,OE,HE,E,(0,1)PERE,PERPE,PEROE,PERHE,TV(9,3)
03080 PRINT  (6,4)P,O,H,T,*,(0,1)PERP,PERO,PERH
03100 PLOT  PA=A,PB=B,PC=C,PD=D,PE=E(0,5E+6)
03110 PLOT  OA=A,OB=B,OC=C,OD=D,OE=E(0,5E+6)
03120 PLOT  HA=A,HB=B,HC=C,HD=D,HE=E(0,5E+6)
03130 PLOT  P=P,O=O,H=H(0,15E+6),T=T(15E+6,25E+6)
03140 PLOT  A=A,B=B,C=C,D=D,E=E(0,15E+6)
03150 PLOT  TSSV=1,THSV=A,TSPV=2,THPV=B(0,15E+9)/TV=T(20E+9,35E+9)
03160 NOTE
03170 NOTE  -------------------------PROGRAM INPUT-------------------------
03180 NOTE
03190 NOTE  STANDING MERCH. CU. VOL. FACTORS
03200 NOTE
03210 A  PASSV.K=PA.K*22
03220 A  PAHSV.K=PA.K*0
03230 A  PASPV.K=PA.K*15
03240 A  PAHPV.K=PA.K*0
03250 A  PBSSV.K=PB.K*62
03260 A  PBHSV.K=PB.K*10
03270 A  PBSPV.K=PB.K*49
03280 A  PBHPV.K=PB.K*11
03290 A  PCSSV.K=PC.K*67
03300 A  PCHSV.K=PC.K*6
03310 A  PCSPV.K=PC.K*124
03320 A  PCHPV.K=PC.K*12
03330 A  PDSSV.K=PD.K*363
03340 A  PDHSV.K=PD.K*28
03350 A  PDSPV.K=PD.K*705
03360 A  PDHPV.K=PD.K*62
03370 A  PESSV.K=PE.K*1561
03380 A  PEHSV.K=PE.K*122
03390 A  PESPV.K=PE.K*281
03400 A  PEHPV.K=PE.K*92
03410 A  OASSV.K=OA.K*66
03420 A  OAHSV.K=OA.K*0
03430 A  OASPV.K=OA.K*0
03440 A  OAHPV.K=OA.K*0
03450 A  OBSSV.K=OB.K*152
03460 A  OBHSV.K=OB.K*33
03470 A  OBSPV.K=OB.K*57
03480 A  OBHPV.K=OB.K*45
03490 A  OCSSV.K=OC.K*207
03500 A  OCHSV.K=OC.K*33
03510 A  OCSPV.K=OC.K*104
03520 A  OCHPV.K=OC.K*20
03530 A  ODSSV.K=OD.K*279
03540 A  ODHSV.K=OD.K*181
03550 A  ODSPV.K=OD.K*264
03560 A  ODHPV.K=OD.K*351
03570 A  OESSV.K=OE.K*804
03580 A  OEHSV.K=OE.K*524
03590 A  OESPV.K=OE.K*95
03600 A  OEHPV.K=OE.K*296
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03610 A  HASSV.K=HA.K*11
03620 A  HAHSV.K=HA.K*13
03630 A  HASPV.K=HA.K*4
03640 A  HAHPV.K=HA.K*15
03650 A  HBSSV.K=HB.K*37
03660 A  HBHSV.K=HB.K*77
03670 A  HBSPV.K=HB.K*25
03680 A  HBHPV.K=HB.K*89
03690 A  HCSSV.K=HC.K*79
03700 A  HCHSV.K=HC.K*103
03710 A  HCSPV.K=HC.K*36
03720 A  HCHPV.K=HC.K*124
03730 A  HDSSV.K=HD.K*104
03740 A  HDHSV.K=HD.K*407
03750 A  HDSPV.K=HD.K*46
03760 A  HDHPV.K=HD.K*663
03770 A  HESSV.K=HE.K*232
03780 A  HEHSV.K=HE.K*1393
03790 A  HESPV.K=HE.K*22
03800 A  HEHPV.K=HE.K*428
03810 C  REMEAS=10.120                    INVENTORY REMEASUREMENT PERIOD (YRS.)
03820 NOTE
03830 NOTE  <<<<<<<<<< TYPE-SIZE BIOLOGICAL RESPONSE TO TREATMENT >>>>>>>>>>
03840 NOTE
03850 NOTE  ***** TREAT. 1-NATURAL SUCCESSION *****    PERIOD RATES (DECIMAL)
03860 NOTE
03870 C  PAPB1=.0000/PAPC1=.5281/PAPD1=.0000/PAPE1=.0000/PAOA1=.0000
03880 C  PAOB1=.2271/PAOC1=.0000/PAOD1=.0000/PAOE1=.0000/PAHA1=.0000
03890 C  PAHB1=.0000/PAHC1=.0000/PAHD1=.0000/PAHE1=.0000/PBPA1=.0000
03900 C  PBPC1=.4567/PBPD1=.3291/PBPE1=.1394/PBOA1=.0000/PBOB1=.0000
03910 C  PBOC1=.0255/PBOD1=.0000/PBOE1=.0000/PBHA1=.0000/PBHB1=.0000
03920 C  PBHC1=.0000/PBHD1=.0119/PBHE1=.0000/PCPA1=.0000/PCPB1=.0000
03930 C  PCPD1=.6572/PCPE1=.0998/PCOA1=.0000/PCOB1=.0000/PCOC1=.0070
03940 C  PCOD1=.0447/PCOE1=.0086/PCHA1=.0000/PCHB1=.0000/PCHC1=.0000
03950 C  PCHD1=.0000/PCHE1=.0000/PDPA1=.0000/PDPB1=.0000/PDPC1=.0133
03960 C  PDPE1=.5256/PDOA1=.0000/PDOB1=.0074/PDOC1=.0128/PDOD1=.0358
03970 C  PDOE1=.0330/PDHA1=.0074/PDHB1=.0000/PDHC1=.0000/PDHD1=.0152
03980 C  PDHE1=.0000/PEPA1=.0000/PEPB1=.0000/PEPC1=.0000/PEPD1=.0578
03990 C  PEOA1=.0000/PEOB1=.0000/PEOC1=.0000/PEOD1=.0000/PEOE1=.0336
04000 C  PEHA1=.0000/PEHB1=.0000/PEHC1=.0062/PEHD1=.0000/PEHE1=.0133
04010 C  OAPA1=.0000/OAPB1=.5013/OAPC1=.0000/OAPD1=.0000/OAPE1=.0000
04020 C  OAOB1=.0000/OAOC1=.0000/OAOD1=.0000/OAOE1=.0000/OAHA1=.4987
04030 C  OAHB1=.0000/OAHC1=.0000/OAHD1=.0000/OAHE1=.0000/OBPA1=.0000
04040 C  OBPB1=.0000/OBPC1=.3220/OBPD1=.0855/OBPE1=.0474/OBOA1=.0000
04050 C  OBOC1=.3009/OBOD1=.0000/OBOE1=.0000/OBHA1=.0000/OBHB1=.0000
04060 C  OBHC1=.1206/OBHD1=.0413/OBHE1=.0411/OCPA1=.0000/OCPB1=.0000
04070 C  OCPC1=.0177/OCPD1=.2392/OCPE1=.0609/OCOA1=.0000/OCOB1=.0000
04080 C  OCOD1=.1789/OCOE1=.0748/OCHA1=.0000/OCHB1=.0000/OCHC1=.0681
04090 C  OCHD1=.1265/OCHE1=.0380/ODPA1=.0000/ODPB1=.0000/ODPC1=.0000
04100 C  ODPD1=.1580/ODPE1=.2020/ODOA1=.0000/ODOB1=.0000/ODOC1=.0000
04110 C  ODOE1=.1770/ODHA1=.0000/ODHB1=.0000/ODHC1=.0000/ODHD1=.0787
04120 C  ODHE1=.1575/OEPA1=.0000/OEPB1=.0129/OEPC1=.0000/OEPD1=.0287
04130 C  OEPE1=.2480/OEOA1=.0000/OEOB1=.0000/OEOC1=.0239/OEOD1=.0129
04140 C  OEHA1=.0000/OEHB1=.0000/OEHC1=.0129/OEHD1=.0546/OEHE1=.1714
04150 C  HAPA1=.0227/HAPB1=.0000/HAPC1=.0229/HAPD1=.0229/HAPE1=.0000
04160 C  HAOA1=.0227/HAOB1=.0439/HAOC1=.0211/HAOD1=.0000/HAOE1=.0227
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04170 C  HAHB1=.0229/HAHC1=.0895/HAHD1=.0963/HAHE1=.0879/HBPA1=.0000
04180 C  HBPB1=.0000/HBPC1=.0737/HBPD1=.0310/HBPE1=.0311/HBOA1=.0000
04190 C  HBOB1=.0288/HBOC1=.0623/HBOD1=.0310/HBOE1=.0380/HBHA1=.0000
04200 C  HBHC1=.3176/HBHD1=.2887/HBHE1=.0979/HCPA1=.0112/HCPB1=.0000
04210 C  HCPC1=.0000/HCPD1=.0000/HCPE1=.0224/HCOA1=.0000/HCOB1=.0000
04220 C  HCOC1=.0129/HCOD1=.0577/HCOE1=.0466/HCHA1=.0112/HCHB1=.0000
04230 C  HCHD1=.3878/HCHE1=.0803/HDPA1=.0000/HDPB1=.0000/HDPC1=.0000
04240 C  HDPD1=.0103/HDPE1=.0064/HDOA1=.0000/HDOB1=.0000/HDOC1=.0000
04250 C  HDOD1=.0445/HDOE1=.0311/HDHA1=.0032/HDHB1=.0037/HDHC1=.0253
04260 C  HDHE1=.4408/HEPA1=.0000/HEPB1=.0000/HEPC1=.0000/HEPD1=.0000
04270 C  HEPE1=.0000/HEOA1=.0000/HEOB1=.0000/HEOC1=.0000/HEOD1=.0086
04280 C  HEOE1=.0389/HEHA1=.0076/HEHB1=.0025/HEHC1=.0086/HEHD1=.1224
04290 NOTE
04300 NOTE
04310 NOTE  TREATMENTS 2-13 OMITTED
04320 NOTE
04330 NOTE
04340 NOTE
04350 NOTE  <<<<<<<<<< TYPE-SIZE DISTRIBUTION OF FOREST BASE CHANGES >>>>>>>>>>
04360 NOTE
04370 NOTE  ***** PLANTED NF ACREAGE RESULTING TYPE-SIZES *****      (DECIMAL)
04380 NOTE
04390 C  PPA=.0311/PPB=.5211/PPC=.2656/PPD=.1822/PPE=.0000
04400 C  POA=.0000/POB=.0000/POC=.0000/POD=.0000/POE=.0000
04410 C  PHA=.0000/PHB=.0000/PHC=.0000/PHD=.0000/PHE=.0000
04420 NOTE
04430 NOTE  ***** REVERTED NF ACREAGE RESULTING TYPE-SIZES *****     (DECIMAL)
04440 NOTE
04450 C  RPA=.0000/RPB=.0931/RPC=.2998/RPD=.1491/RPE=.0600
04460 C  ROA=.0000/ROB=.0361/ROC=.0516/ROD=.0000/ROE=.0000
04470 C  RHA=.0261/RHB=.0486/RHC=.1731/RHD=.0624/RHE=.0000
04480 NOTE
04490 NOTE  ***** CLEARED TO NONFOREST BY INITIAL TYPE-SIZE *****    (DECIMAL)
04500 NOTE
04510 C  CPA=.0208/CPB=.0215/CPC=.1082/CPD=.2087/CPE=.1664
04520 C  COA=.0040/COB=.0134/COC=.0450/COD=.0253/COE=.0552
04530 C  CHA=.0831/CHB=.0333/CHC=.0559/CHD=.0997/CHE=.0594
04540 NOTE
04550 NOTE  <<<<<<<<<< ANALYTICAL CONTROLS >>>>>>>>>>
04560 NOTE
04570 NOTE  ***** FOREST BASE CHANGES *****                    (ANNUAL ACRES)
04580 NOTE
04590 C  TAPA=9239.8                          NONFOREST ACRES PLANTED ANNUALLY
04600 C  TARA=27173.2                       NONFOREST ACRES REVERTING ANNUALLY
04610 C  TACA=144387.4                          FOREST ACRES CLEARED ANNUALLY
04620 NOTE
04630 NOTE  ***** INITIAL INVENTORY ACREAGE *****                (TOTAL ACRES)
04640 NOTE
04650 C  IPA=205658/IPB=1232882/IPC=1787115/IPD=3769165/IPE=4444099
04660 C  IOA=37998/IOB=458372/IOC=476945/IOD=923878/IOE=1062357
04670 C  IHA=449893/IHB=678457/IHC=1176027/IHD=3028577/IHE=4002261
04680 NOTE
04690 NOTE  ***** PERCENT OF INITIAL ACRES UNDERGOING TREATMENT *****(DECIMAL)
04700 NOTE
04710 NOTE  PINE NONSTOCKED
04720 C  PATD1=.2721/PATD2=.1998/PATD3=.0000/PATD4=.0666
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04730 C  PATD5=.0000/PATD6=.2616/PATD7=.0000/PATD8=.0000
04740 C  PATD9=.1998/PATD10=.0000/PATD11=.0000/PATD12=.0000/PATD13=.0000
04750 NOTE  PINE SEEDLING
04760 C  PBTD1=.4349/PBTD2=.0206/PBTD3=.0210/PBTD4=.0571
04770 C  PBTD5=.0000/PBTD6=.0412/PBTD7=.0424/PBTD8=.0162
04780 C  PBTD9=.1490/PBTD10=.1464/PBTD11=.0155/PBTD12=.0199/PBTD13=.0357
04790 NOTE  PINE SAPLING
04800 C  PCTD1=.3225/PCTD2=.0289/PCTD3=.0141/PCTD4=.0582
04810 C  PCTD5=.0120/PCTD6=.0091/PCTD7=.0943/PCTD8=.0448
04820 C  PCTD9=.1482/PCTD10=.1843/PCTD11=.0302/PCTD12=.0094/PCTD13=.0440
04830 NOTE  PINE POLETIMBER
04840 C  PDTD1=.2180/PDTD2=.0996/PDTD3=.0664/PDTD4=.1237
04850 C  PDTD5=.0113/PDTD6=.0073/PDTD7=.0913/PDTD8=.0922
04860 C  PDTD9=.0635/PDTD10=.1125/PDTD11=.0717/PDTD12=.0177/PDTD13=.0247
04870 NOTE  PINE SAWTIMBER
04880 C  PETD1=.2431/PETD2=.1244/PETD3=.0889/PETD4=.1213
04890 C  PETD5=.0284/PETD6=.0015/PETD7=.1055/PETD8=.0317
04900 C  PETD9=.0820/PETD10=.0438/PETD11=.0747/PETD12=.0104/PETD13=.0442
04910 NOTE  OAK-PINE NONSTOCKED
04920 C  OATD1=.2830/OATD2=.0000/OATD3=.0000/OATD4=.2823
04930 C  OATD5=.0000/OATD6=.0000/OATD7=.0000/OATD8=.0000
04940 C  OATD9=.2936/OATD10=.0000/OATD11=.0000/OATD12=.1411/OATD13=.0000
04950 NOTE  OAK-PINE SEEDLING
04960 C  OBTD1=.5045/OBTD2=.0208/OBTD3=.0000/OBTD4=.0829
04970 C  OBTD5=.0207/OBTD6=.1039/OBTD7=.0208/OBTD8=.0000
04980 C  OBTD9=.0592/OBTD10=.0831/OBTD11=.0208/OBTD12=.0208/OBTD13=.0623
04990 NOTE  OAK-PINE SAPLING
05000 C  OCTD1=.4887/OCTD2=.0272/OCTD3=.0086/OCTD4=.0731
05010 C  OCTD5=.0259/OCTD6=.0353/OCTD7=.1217/OCTD8=.0000
05020 C  OCTD9=.0846/OCTD10=.0372/OCTD11=.0806/OCTD12=.0000/OCTD13=.0172
05030 NOTE  OAK-PINE POLETIMBER
05040 C  ODTD1=.4053/ODTD2=.0483/ODTD3=.0568/ODTD4=.0691
05050 C  ODTD5=.0396/ODTD6=.0000/ODTD7=.1170/ODTD8=.0043
05060 C  ODTD9=.0090/ODTD10=.0608/ODTD11=.1169/ODTD12=.0231/ODTD13=.0499
05070 NOTE  OAK-PINE SAWTIMBER
05080 C  OETD1=.3860/OETD2=.0411/OETD3=.0376/OETD4=.1270
05090 C  OETD5=.0867/OETD6=.0000/OETD7=.0703/OETD8=.0218
05100 C  OETD9=.0288/OETD10=.0200/OETD11=.0835/OETD12=.0414/OETD13=.0558
05110 NOTE  HARDWOOD NONSTOCKED
05120 C  HATD1=.4632/HATD2=.0211/HATD3=.0000/HATD4=.0836
05130 C  HATD5=.0203/HATD6=.2144/HATD7=.0211/HATD8=.0000
05140 C  HATD9=.0203/HATD10=.0106/HATD11=.0000/HATD12=.0203/HATD13=.1251
05150 NOTE  HARDWOOD SEEDLING
05160 C  HBTD1=.4674/HBTD2=.0146/HBTD3=.0134/HBTD4=.0447
05170 C  HBTD5=.0000/HBTD6=.1651/HBTD7=.0705/HBTD8=.0000
05180 C  HBTD9=.0682/HBTD10=.0000/HBTD11=.0177/HBTD12=.0479/HBTD13=.0904
05190 NOTE  HARDWOOD SAPLING
05200 C  HCTD1=.5706/HCTD2=.0394/HCTD3=.0187/HCTD4=.0133
05210 C  HCTD5=.0183/HCTD6=.0252/HCTD7=.0910/HCTD8=.0128
05220 C  HCTD9=.0644/HCTD10=.0142/HCTD11=.0064/HCTD12=.0074/HCTD13=.1185
05230 NOTE  HARDWOOD POLETIMBER
05240 C  HDTD1=.6392/HDTD2=.0129/HDTD3=.0064/HDTD4=.0427
05250 C  HDTD5=.0361/HDTD6=.0082/HDTD7=.0978/HDTD8=.0041
05260 C  HDTD9=.0107/HDTD10=.0429/HDTD11=.0262/HDTD12=.0390/HDTD13=.0337
05270 NOTE  HARDWOOD SAWTIMBER
05280 C  HETD1=.6925/HETD2=.0126/HETD3=.0226/HETD4=.0566
```

```
05290 C  HETD5=.0526/HETD6=.0000/HETD7=.0695/HETD8=.0016
05300 C  HETD9=.0016/HETD10=.0298/HETD11=.0110/HETD12=.0209/HETD13=.0288
05310 RUN BASE PROJECTION STRADDLERS OUT 1982-1992
END OF DATA
```

Program Technical Notes

Outlined below is a brief description of the major sectors of the model. In the interest of space, it is impractical to individually define the thousands of variable names used by the program. Many are repetitious and can be deciphered by means of a simple relationship:

Forest Type	Stand Size
P = pine	A = nonstocked
O = oak-pine	B = seedling
H = hardwood	C = sapling
	D = poletimber
	E = sawtimber

Combinations of the above codes are used to define forest-type/stand-size combinations; i.e., PA = pine nonstocked, PB = pine seedlings ,..., HE = hardwood sawtimber. These coding combinations form the roots of most variable names. The specific variable names necessary to understand the program are provided in order of occurrence as each sector is described.

Forest-to-Forest Sector (lines 10-1550)

The entire forest-to-forest sector is controlled by the macros RTOTYP and TYPBTR (lines 10-400). These macros tabulate each type-size treatment level, are made up of dummy variables, and are defined by the 13 treatment blocks directly below them. In this listing, only treatment 1 is shown (lines 420-1480). Each type-size combination under each of the 13 treatment blocks invokes and defines the macros. Variable names for the treatment 1 pine nonstocked combination (lines 440-500) are defined as follows:

PA1 = pine nonstocked treatment 1 level.
IPA = initial pine nonstocked acreage inventory.
CPA = the percentage of all acres cleared annually which are pine nonstocked.
PATD1 = the percentage of initial pine nonstocked acres to experience treatment 1.
PAPB1 = the percentage of initial pine nonstocked acres dispersed from pine nonstocked to pine seedling under treatment 1.
PAPC1 = the percentage of initial pine nonstocked acres dispersed from pine nonstocked to pine sapling under treatment 1.
.
.
.
PAHE1 = the percentage of initial pine nonstocked acres dispersed from pine nonstocked to hardwood sawtimber under treatment 1.
PBPA1 = the percentage of initial pine seedling acres dispersed from pine seedling to pine nonstocked under treatment 1.
PCPA1 = the percentage of initial pine sapling acres dispersed from pine sapling to pine nonstocked under treatment 1.
.
.
.
HEPA1 = the percentage of initial hardwood sawtimber acres dispersed from hardwood sawtimber to pine nonstocked under treatment 1.

FFPB1 = the amount of initial pine seedling acres which are to experience
. treatment 1 that are to remain in forest over the model run.
.
.
FFHE1 = the amount of initial hardwood sawtimber acres which are to experience treatment 1 that are to remain in forest over the model run.
FFPA1 = the amount of initial pine nonstocked acres which are to experience treatment 1 that are to remain in forest over the model run.

Forest Land-Base Change Sector (lines 1560-2020)

The 15 levels and rates listed here keep track of all additions to and subtractions from the forest land base. Variable names for the pine nonstocked land-base change level (lines 1580-1600) are defined as follows:

NLBCPA = pine nonstocked net land-base change level.
RLBCPA = pine nonstocked annual rate of land-base change.
CPA = the percentage of all acres cleared annually which are pine nonstocked.
TACA = total acres cleared annually (all type-size combinations).
REMEAS = the number of years separating the initial and final surveys.
PPA = the percentage of all nonforest acres planted annually resulting in pine nonstocked.
TAPA = the total nonforest acres planted annually (all type-size combinations).
RPA = the percentage of all nonforest acres annually reverting naturally to pine nonstocked.
TARA = the total nonforest acres reverting naturally to forest (all type-size combinations).

Summation of Type-Sizes for Output (lines 2040-2670)

Here the type-size combinations under each treatment are summed to calculate the 15 net total forest-type and stand-size levels (lines 2060-2350). Land-base change levels are also included in these equations. The net type-size level equations are constrained by a MAX function to prohibit them from falling below 0. Additional auxiliary equations for program output are calculated in this sector also (lines 2360-2670).

Equations to Stop Run if Level Falls Below 0 (lines 2690-2850)

In the rare instance that a user might specify a set of circumstances which cause a type-size level to fall below 0, these equations will stop the run because results are unpredictable.

Summation of Standing Merchantable Cubic Volume (ft^3) (lines 2870-2970)

Although not part of the core model, these equations were used to produce the volume output presented in table 4 and Appendix B. Variable name root modifiers are defined as follows:

SSV = softwood sawtimber volume.
HSV = hardwood sawtimber volume.
SPV = softwood poletimber volume.
HPV = hardwood poletimber volume.

Model Controls (lines 2990-3150)

Equations controlling the length of the model run, DT interval, scaling of output variables, etc., are listed here. The model length should not be

greater than the Survey remeasurement period because results are unpredictable (line 3020). If the user desires to run the model more than 10 years into the future, the final inventory values of the previous 10-year run should be used as initial values for the next 10-year run.

Program Input (lines 3170-5310)

In this section, all variables used in the model are assigned values. These values are unique to each user-defined region and are screened from Survey plot data. All values listed here apply to the State of Georgia between the years of 1972 and 1982. The type-size biological response to treatment dispersion rates for treatments 2-13 were omitted to conserve space.

Analytical Controls

All variables recommended for manipulation by the user are listed in lines 4550-5310 of the program.

Forest Base Changes (lines 4570-4610)

These values represent annual changes in the forest land base. The numbers presented in the program listing are the amount and type of change measured in Georgia between 1972 and 1982. The user can change these values according to perceptions of the future.

Initial Inventory Acreage (lines 4630-4670)

These values represent the type-size breakdown of the regional inventory at the beginning of the model run. The values shown in the program listing are the inventory breakdown as measured by the 1982 multiresource inventory of Georgia. These initial inventory values were used to project the Georgia inventory from 1982 to 1992. To project the model another 10 years, these values should be replaced with the 1992 projection inventory values.

Percent of Initial Acres Undergoing Treatment (lines 4690-5310)

The most powerful analytical controls are located in this section of the program. It is here that the user can change assumptions about what percentage of each of the 15 initial forest-type and stand-size combinations experience each of the 13 treatments/disturbances. The values presented in the program listing are the rates of treatment measured in Georgia between 1972 and 1982. To change the proportion of the inventory experiencing a particular treatment or disturbance, all the user need do is increase the percentage of acres experiencing one treatment and decrease the percentage of acres experiencing another treatment. For example, if one perceives that the rate of pine poletimber acres experiencing commercial thinning (treatment 8) will increase by 25 percent, one should increase the value of PDTD8 by 25 percent, and decrease the value of PDTD1 by the same amount. This change loads the model with the assumption that the increase in commercially thinned pine poletimber acres will come from pine poletimber acres that otherwise would have experienced no treatment or disturbance. NOTE: The 13 treatment/disturbance rates under each of the type-size combinations should always add to 1 (within rounding); i.e., PATD1 + PATD2 + ,..., + PATD13 = 1.0.

Using the Model

It is important to keep in mind that when one assigns a percentage of the initial inventory to experience a treatment/disturbance, it is the forest type and stand size at the time of the initial inventory (year 0 of the model run) to which the treatment rate is assigned. For instance, when acres of pine poletimber at year 0 are destined to experience commercial thinning, some may

grow into pine sawtimber before the thinning is administered. The model automatically takes this into account, so the user need be concerned only with the composition of the initial inventory, and not all of the complex changes that take place before treatment are actually carried out.

DYNARIP can be used to project a regional inventory any number of years into the future. However, as the model proceeds further into the future, the results become correspondingly less reliable because our assumptions become less reliable. Also, the treatment/disturbance patterns associated with the sawtimber stand sizes may become less dependable if the median age of the trees within these projected classes deviates very far from the median stand age at the time of inventory. The sawtimber stand sizes are susceptible to such slippage because they encompass a potentially wide range of stand ages.

DYNARIP rates of change are based on 10-year rates between two points in time. For this reason, once a set of assumptions is entered, the model should be allowed to run for a 10-year timespan before any assumptions are changed. This allows the 10-year rates built into the model to exert their full impact on the inventory. Assumptions can be changed to any degree desired, but only at 10-year intervals.

The model uses a combination of differential and linear rates of change. On a decade basis, the DYNAMO simulation translates the empirical rates of change into differential rates. Between decades, on an annual basis, the empirical rates are treated as linear rates of change since this is all that can be inferred from inventories at two points in time. In reality, most of these annual rates are not linear, but we do not know their true form. Although the model outputs inventory values for all intermediate years for each 10-year run, these intermediate values should be used cautiously with the knowledge that the deviation between the assumed linear rate and the true rate is unknown. Year 10 is therefore the most reliable year of any DYNARIP simulation.

Appendix B.

Georgia 1982-1992 Base-Run Sample Output

The following tables and graphs are a sample of the output produced by the DYNARIP base-run projection for Georgia. The base run assumes that all rates measured between 1972 and 1982 will remain unchanged between 1982 and 1992. Growing-stock inventory volume projections have been added to the core model acreage simulation.

Table 5.--DYNARIP base-run area and growing-stock volume projections, Georgia, 1982-1992

	Variable name[a]								
TIME	PA	OA	HA	A	PERA	PERPA	PEROA	PERHA	TSSV
	PB	OB	HB	B	PERB	PERPB	PEROB	PERHB	THSV
	PC	OC	HC	C	PERC	PERPC	PEROC	PERHC	TSPV
	PD	OD	HD	D	PERD	PERPD	PEROD	PERHD	THPV
	PE	OE	HE	E	PERE	PERPE	PEROE	PERHE	TV
	P	O	H	T		PERP	PERO	PERH	
	Scale								
	Acres				Percent				Cubic feet
E+00	E+03	E+03	E+03	E+03	E+00	E+00	E+00	E+00	E+09
	E+03	E+03	E+03	E+03	E+00	E+00	E+00	E+00	E+09
	E+03	E+03	E+03	E+03	E+00	E+00	E+00	E+00	E+09
	E+03	E+03	E+03	E+03	E+00	E+00	E+00	E+00	E+09
	E+03	E+03	E+03	E+03	E+00	E+00	E+00	E+00	E+09
	E+06	E+06	E+06	E+06		E+00	E+00	E+00	
1982	205.64	37.998	449.89	693.53	2.9	0.9	0.2	1.9	11.155
	1232.8	458.28	678.39	2369.4	10.0	5.2	1.9	2.9	8.413
	1787.1	476.99	1176.2	3440.3	14.5	7.5	2.0	5.0	4.900
	3768.8	923.97	3028.3	7721.1	32.5	15.9	3.9	12.8	5.280
	4443.7	1062.4	4002.6	9508.7	40.1	18.7	4.5	16.9	29.748
	11.44M	2.9596	9.3355	23.73M		48.2	12.5	39.3	
1983	206.87	37.997	448.16	693.02	2.9	.9	.2	1.9	11.068
	1231.0	454.07	671.50	2356.6	10.0	5.2	1.9	2.8	8.469
	1794.3	473.33	1166.8	3434.4	14.5	7.6	2.0	4.9	4.834
	3694.8	913.21	3017.3	7625.3	32.3	15.6	3.9	12.8	5.279
	4407.5	1050.2	4058.0	9515.7	40.3	18.7	4.4	17.2	29.651
	11.33M	2.9288	9.3617	23.63M		48.0	12.4	39.6	
1984	208.09	37.996	446.42	692.51	2.9	.9	.2	1.9	10.982
	1229.3	449.85	664.61	2343.8	10.0	5.2	1.9	2.8	8.525
	1801.5	469.68	1157.3	3428.4	14.6	7.7	2.0	4.9	4.768
	3620.9	902.46	3006.2	7529.6	32.0	15.4	3.8	12.8	5.278
	4371.4	1038.1	4113.3	9522.8	40.5	18.6	4.4	17.5	29.553
	11.23M	2.8980	9.3879	23.52M		47.8	12.3	39.9	
1985	209.32	37.995	444.68	692.00	3.0	.9	.2	1.9	10.896
	1227.6	445.63	657.72	2331.0	10.0	5.2	1.9	2.8	8.581
	1808.6	466.02	1147.8	3422.4	14.6	7.7	2.0	4.9	4.702
	3546.9	891.71	2995.2	7433.8	31.8	15.2	3.8	12.8	5.278
	4335.3	1025.9	4168.7	9529.9	40.7	18.5	4.4	17.8	29.456
	11.13M	2.8673	9.4141	23.41M		47.5	12.2	40.2	

Continued

Table 5.--DYNARIP base-run area and growing-stock volume projections, Georgia, 1982-1992--Continued

TIME	PA PB PC PD PE P	OA OB OC OD OE O	HA HB HC HD HE H	A B C D E T	PERA PERB PERC PERD PERE	PERPA PERPB PERPC PERPD PERPE PERP	PEROA PEROB PEROC PEROD PEROE PERO	PERHA PERHB PERHC PERHD PERHE PERH	TSSV THSV TSPV THPV TV
1986	210.55	37.994	442.94	691.48	3.0	.9	.2	1.9	10.809
	1225.9	441.41	650.83	2318.1	9.9	5.3	1.9	2.8	8.637
	1815.8	462.37	1138.3	3416.5	14.7	7.8	2.0	4.9	4.636
	3472.9	880.95	2984.2	7338.1	31.5	14.9	3.8	12.8	5.277
	4299.1	1013.8	4224.0	9536.9	40.9	18.5	4.4	18.1	29.359
	11.02M	2.8365	9.4403	23.30M		47.3	12.2	40.5	
1987	211.77	37.992	441.21	690.97	3.0	.9	.2	1.9	10.723
	1224.2	437.20	643.94	2305.3	9.9	5.3	1.9	2.8	8.693
	1823.0	458.71	1128.8	3410.5	14.7	7.9	2.0	4.9	4.570
	3399.0	870.20	2973.2	7242.4	31.2	14.7	3.8	12.8	5.276
	4263.0	1001.6	4279.4	9544.0	41.2	18.4	4.3	18.5	29.262
	10.92M	2.8057	9.4665	23.19M		47.1	12.1	40.8	
1988	213.00	37.991	439.47	690.46	3.0	.9	.2	1.9	10.637
	1222.5	432.98	637.05	2292.5	9.9	5.3	1.9	2.8	8.749
	1830.1	455.06	1119.4	3404.5	14.7	7.9	2.0	4.8	4.504
	3325.0	859.45	2962.2	7146.6	31.0	14.4	3.7	12.8	5.275
	4226.9	989.5	4334.7	9551.0	41.4	18.3	4.3	18.8	29.165
	10.82M	2.7750	9.4928	23.09M		46.9	12.0	41.1	
1989	214.22	37.990	437.73	689.95	3.0	.9	.2	1.9	10.550
	1220.7	428.76	630.16	2279.7	9.9	5.3	1.9	2.7	8.805
	1837.3	451.40	1109.9	3398.6	14.8	8.0	2.0	4.8	4.439
	3251.0	848.70	2951.2	7050.9	30.7	14.1	3.7	12.8	5.274
	4190.7	977.3	4390.0	9558.1	41.6	18.2	4.3	19.1	29.068
	10.71M	2.7442	9.5190	22.98M		46.6	11.9	41.4	
1990	215.45	37.989	436.00	689.44	3.0	.9	.2	1.9	10.464
	1219.0	424.54	623.27	2266.8	9.9	5.3	1.9	2.7	8.861
	1844.5	447.75	1100.4	3392.6	14.8	8.1	2.0	4.8	4.373
	3177.1	837.94	2940.1	6955.1	30.4	13.9	3.7	12.9	5.273
	4154.6	965.2	4445.4	9565.2	41.8	18.2	4.2	19.4	28.971
	10.61M	2.7134	9.5452	22.87M		46.4	11.9	41.7	
1991	216.68	37.988	434.26	688.93	3.0	1.0	.2	1.9	10.378
	1217.3	420.32	616.38	2254.0	9.9	5.3	1.8	2.7	8.917
	1851.6	444.10	1090.9	3386.7	14.9	8.1	2.0	4.8	4.307
	3103.1	827.19	2929.1	6859.4	30.1	13.6	3.6	12.9	5.272
	4118.5	953.0	4500.7	9572.2	42.1	18.1	4.2	19.8	28.874
	10.51M	2.6826	9.5714	22.76M		46.2	11.8	42.1	

Continued

Table 5.--DYNARIP base-run area and growing-stock volume projections, Georgia, 1982-1992--Continued

TIME	PA	OA	HA	A	PERA	PERPA	PEROA	PERHA	TSSV
	PB	OB	HB	B	PERB	PERPB	PEROB	PERHB	THSV
	PC	OC	HC	C	PERC	PERPC	PEROC	PERHC	TSPV
	PD	OD	HD	D	PERD	PERPD	PEROD	PERHD	THPV
	PE	OE	HE	E	PERE	PERPE	PEROE	PERHE	TV
	P	O	H	T		PERP	PERO	PERH	
1992	217.90	37.987	432.52	688.41	3.0	1.0	.2	1.9	10.291
	1215.6	416.11	609.49	2241.2	9.9	5.4	1.8	2.7	8.973
	1858.8	440.44	1081.4	3380.7	14.9	8.2	1.9	4.8	4.241
	3029.1	816.44	2918.1	6763.7	29.9	13.4	3.6	12.9	5.271
	4082.3	940.9	4556.1	9579.3	42.3	18.0	4.2	20.1	28.777
	10.40M	2.6519	9.5976	22.65M		45.9	11.7	42.4	

[a]Variable name definitions:

PA = pine nonstocked
PB = pine seedling
PC = pine sapling
PD = pine poletimber
PE = pine sawtimber
P = pine

OA = oak-pine nonstocked
OB = oak-pine seedling
OC = oak-pine sapling
OD = oak-pine poletimber
OE = oak-pine sawtimber
O = all oak-pine

HA = hardwood nonstocked
HB = hardwood seedling
HC = hardwood sapling
HD = hardwood poletimber
HE = hardwood sawtimber
H = all hardwood

A = all nonstocked
B = all seedling
C = all sapling
D = all poletimber
E = all sawtimber
T = total commercial forest

PERA = percentage of all nonstocked
PERB = percentage of all seedling
PERC = percentage of all sapling
PERD = percentage of all poletimber
PERE = percentage of all sawtimber

PERPA = percentage of pine nonstocked
PERPB = percentage of pine seedling
PERPC = percentage of pine sapling
PERPD = percentage of pine poletimber
PERE = percentage of pine sawtimber
PERP = percentage of all pine

PEROA = percentage of oak-pine nonstocked
PEROB = percentage of oak-pine seedling
PEROC = percentage of oak-pine sapling
PEROD = percentage of oak-pine poletimber
PEROE = percentage of oak-pine sawtimber
PERO = percentage of all oak-pine

PERHA = percentage of hardwood nonstocked
PERHB = percentage of hardwood seedling
PERHC = percentage of hardwood sapling
PERHD = percentage of hardwood poletimber
PERHE = percentage of hardwood sawtimber
PERH = percentage of all hardwood

TSSV = softwood sawtimber volume
THSV = hardwood sawtimber volume
TSPV = softwood poletimber volume
THPV = hardwood poletimber volume
TV = total growing-stock volume

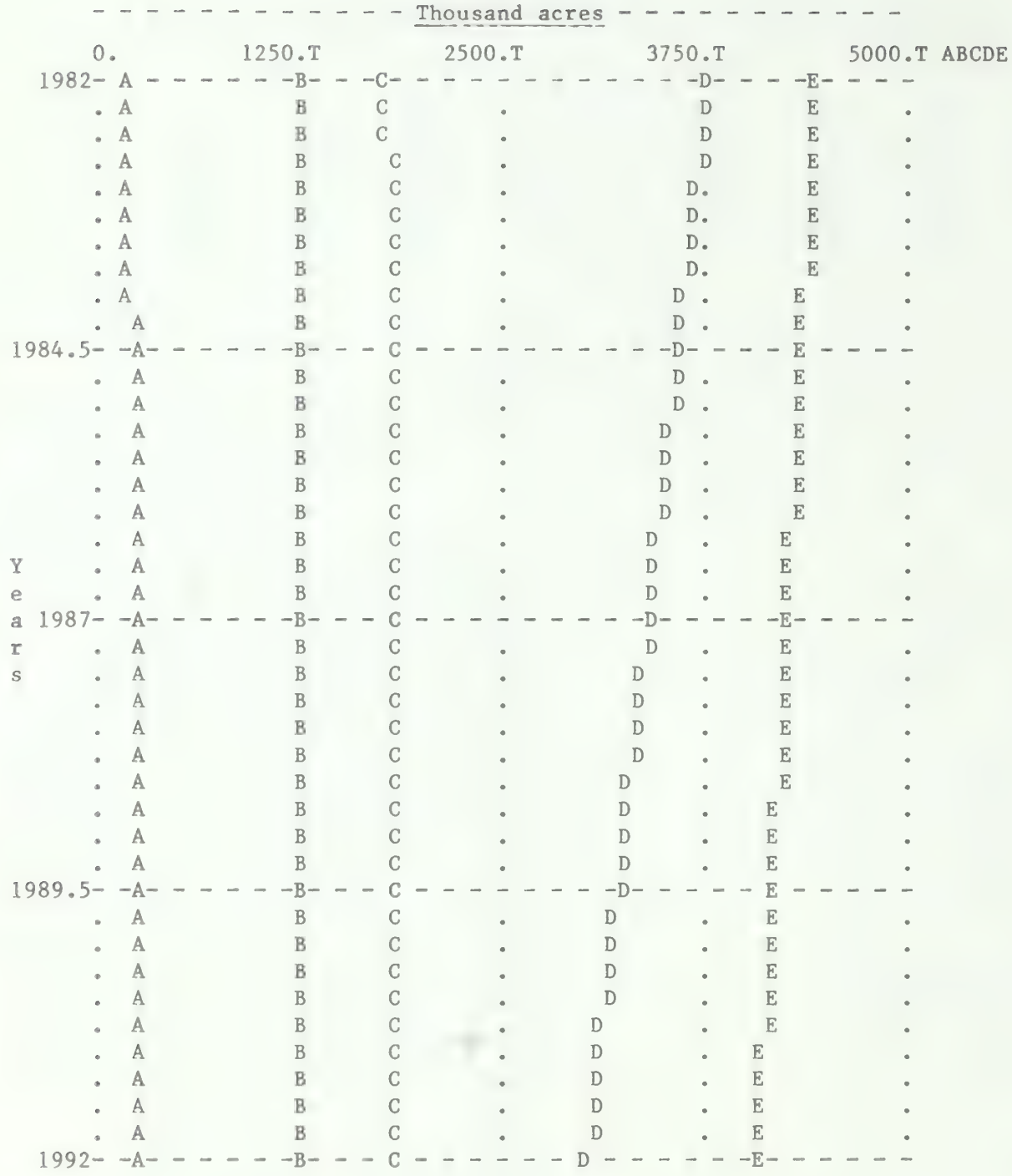

Figure 5.--DYNARIP base-run area projection of pine forest types by stand size, Georgia, 1982-1992. A = pine nonstocked, B = pine seedling, C = pine sapling, D = pine poletimber, E = pine sawtimber.

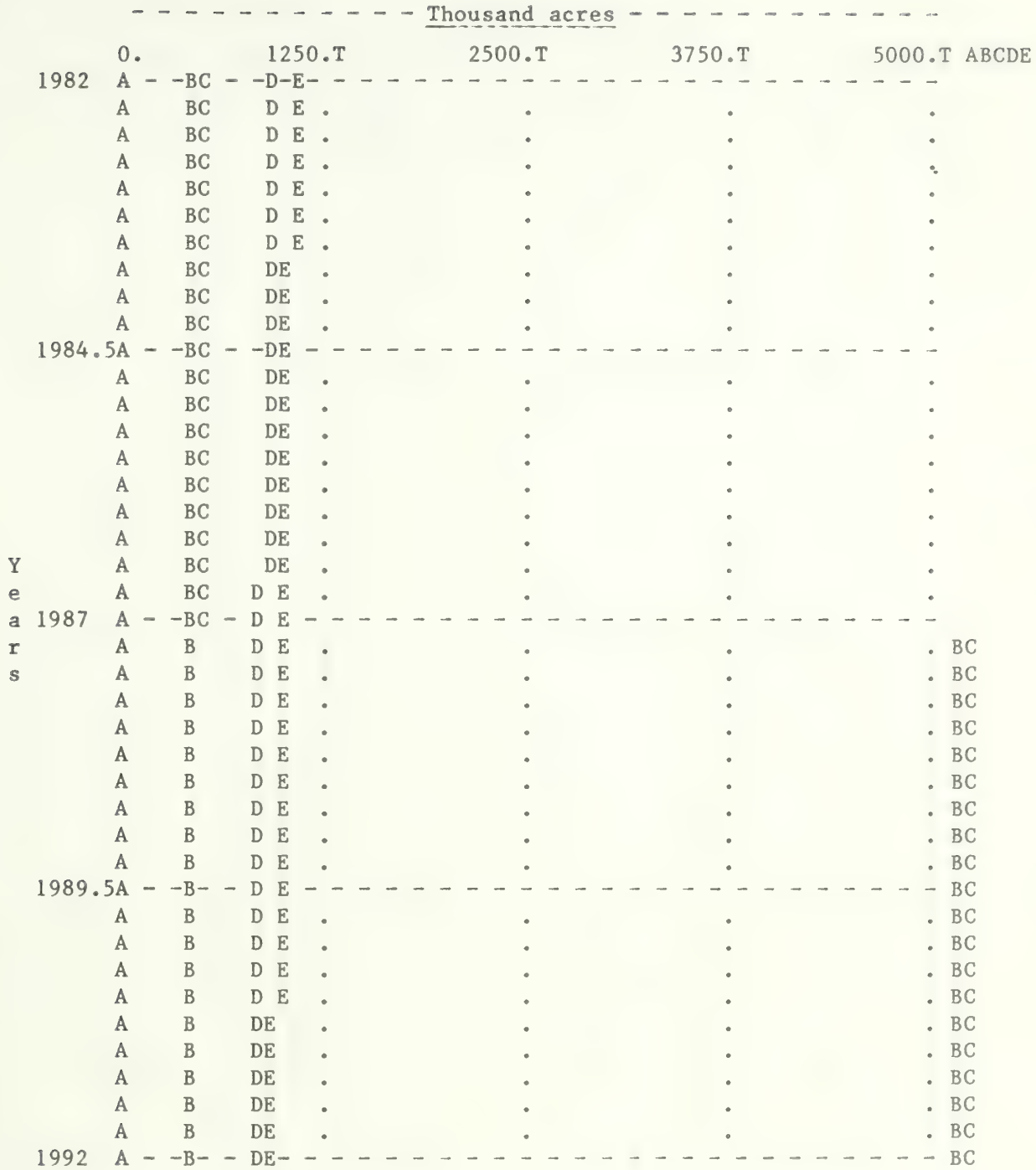

Figure 6.--DYNARIP base-run area projection of the oak-pine forest type, by stand size, Georgia, 1982-1992. A = oak-pine nonstocked, B = oak-pine seedling, C = oak-pine sapling, D = oak-pine poletimber, E = oak-pine sawtimber.

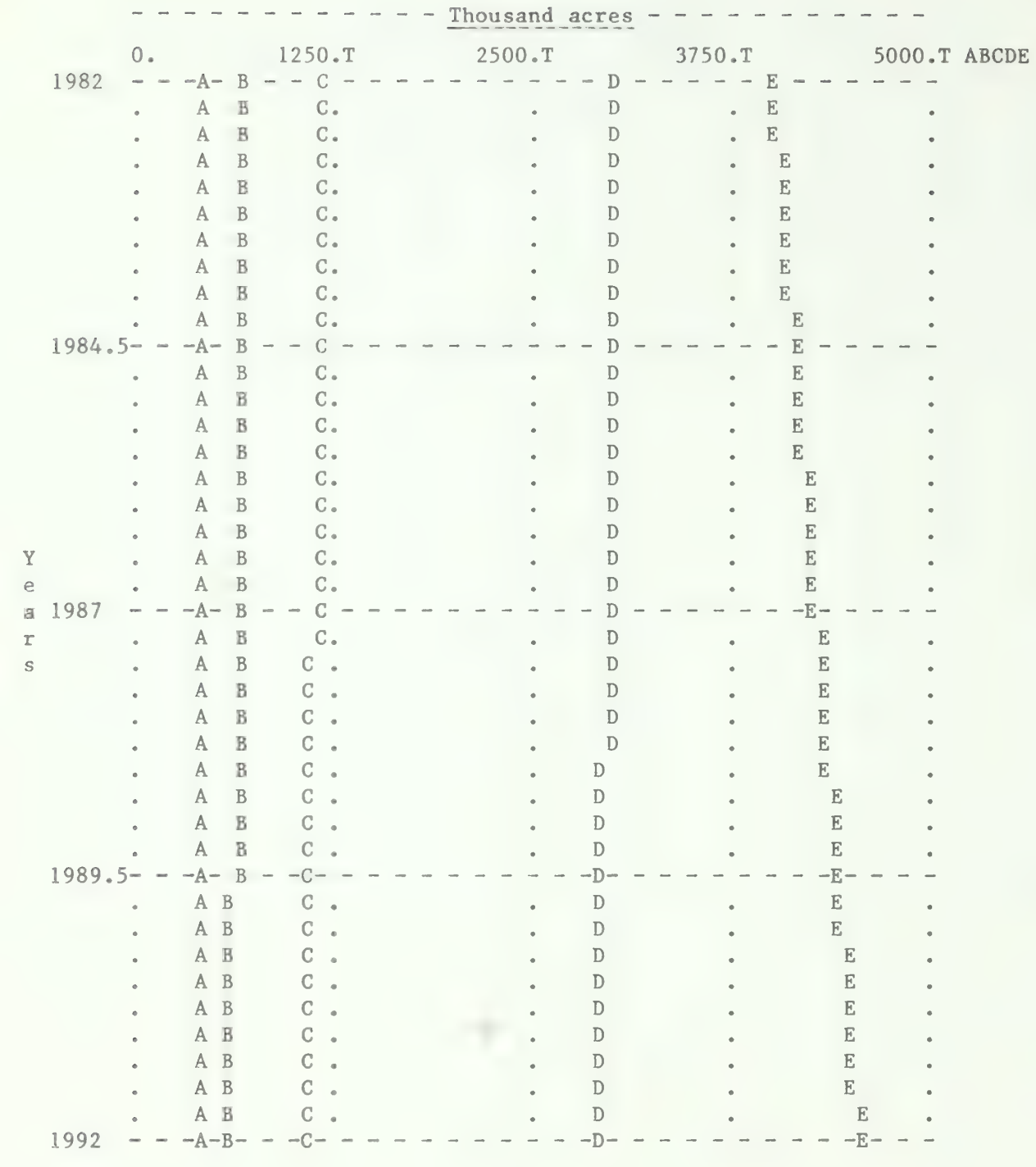

Figure 7.--DYNARIP base-run area projection of hardwood forest types, by stand size, Georgia, 1982-1992. A = hardwood nonstocked, B = hardwood seedling, C = hardwood sapling, D = hardwood poletimber, E = hardwood sawtimber.

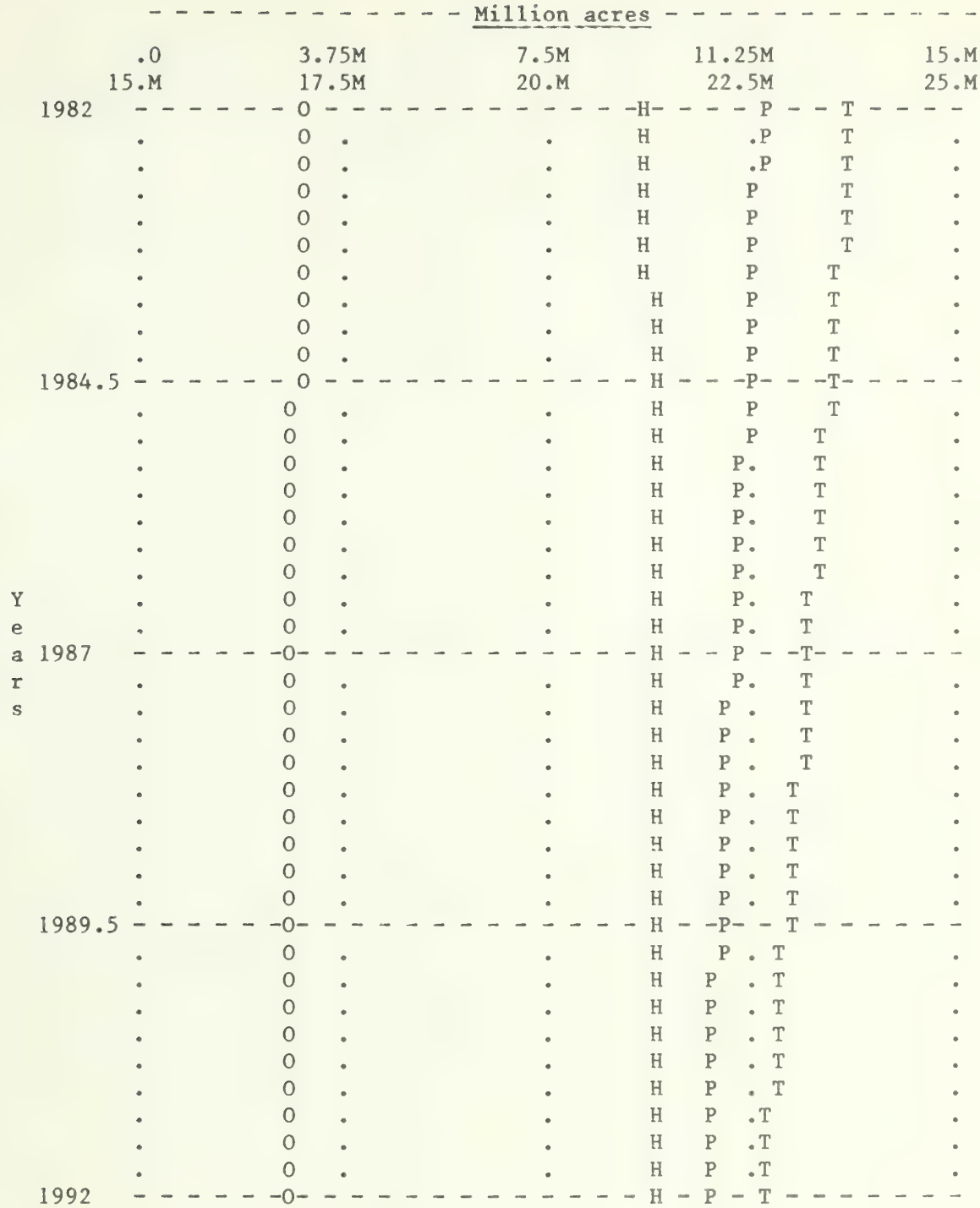

Figure 8.--DYNARIP base-run area projection of all broad forest types, Georgia, 1982-1992. P = pine, O = oak-pine, H = hardwood, T = total.

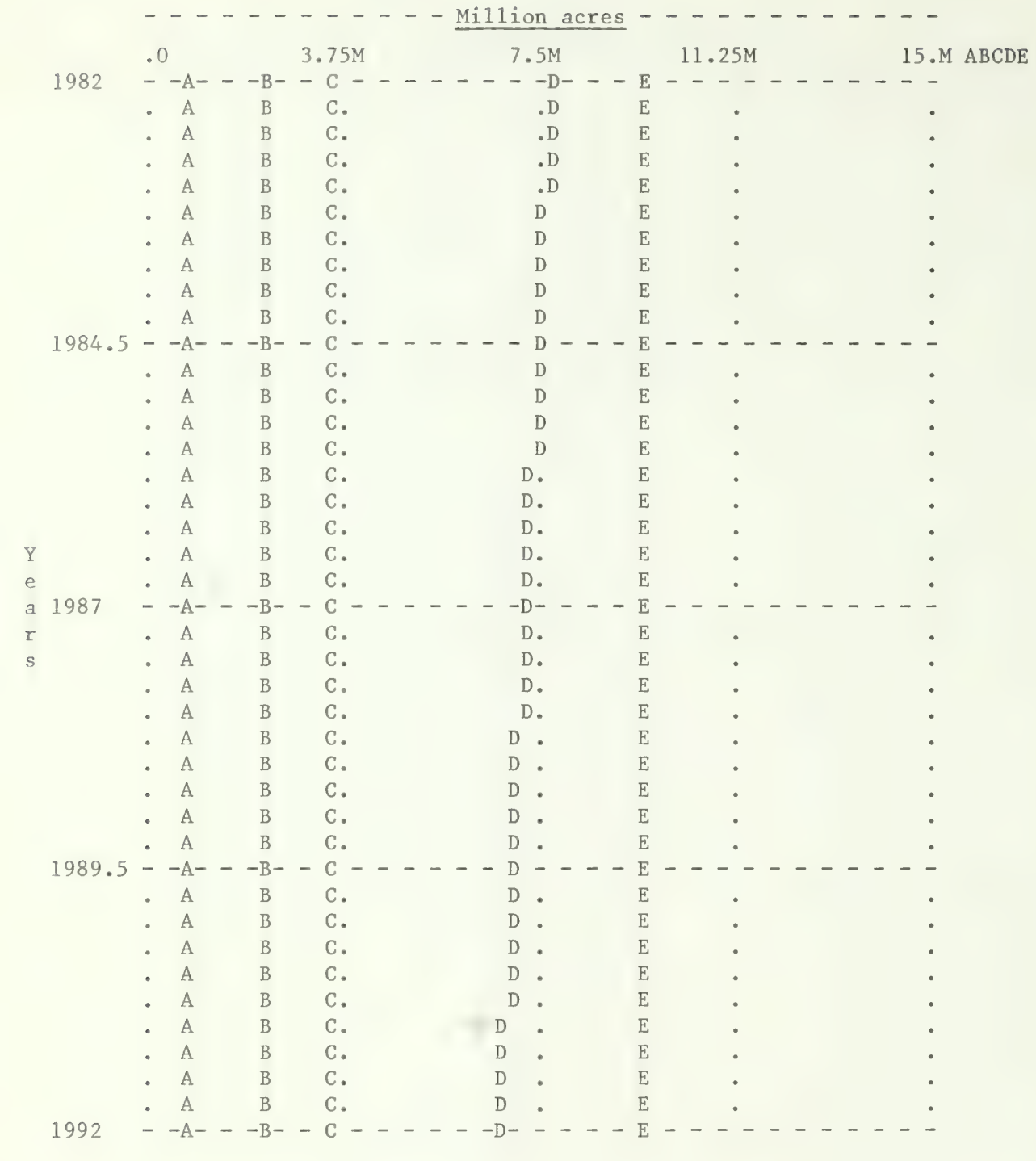

Figure 9.--DYNARIP base-run area projection of all stand-size classes, Georgia, 1982-1992. A = nonstocked, B = seedling, C = sapling, D = poletimber, E = sawtimber.

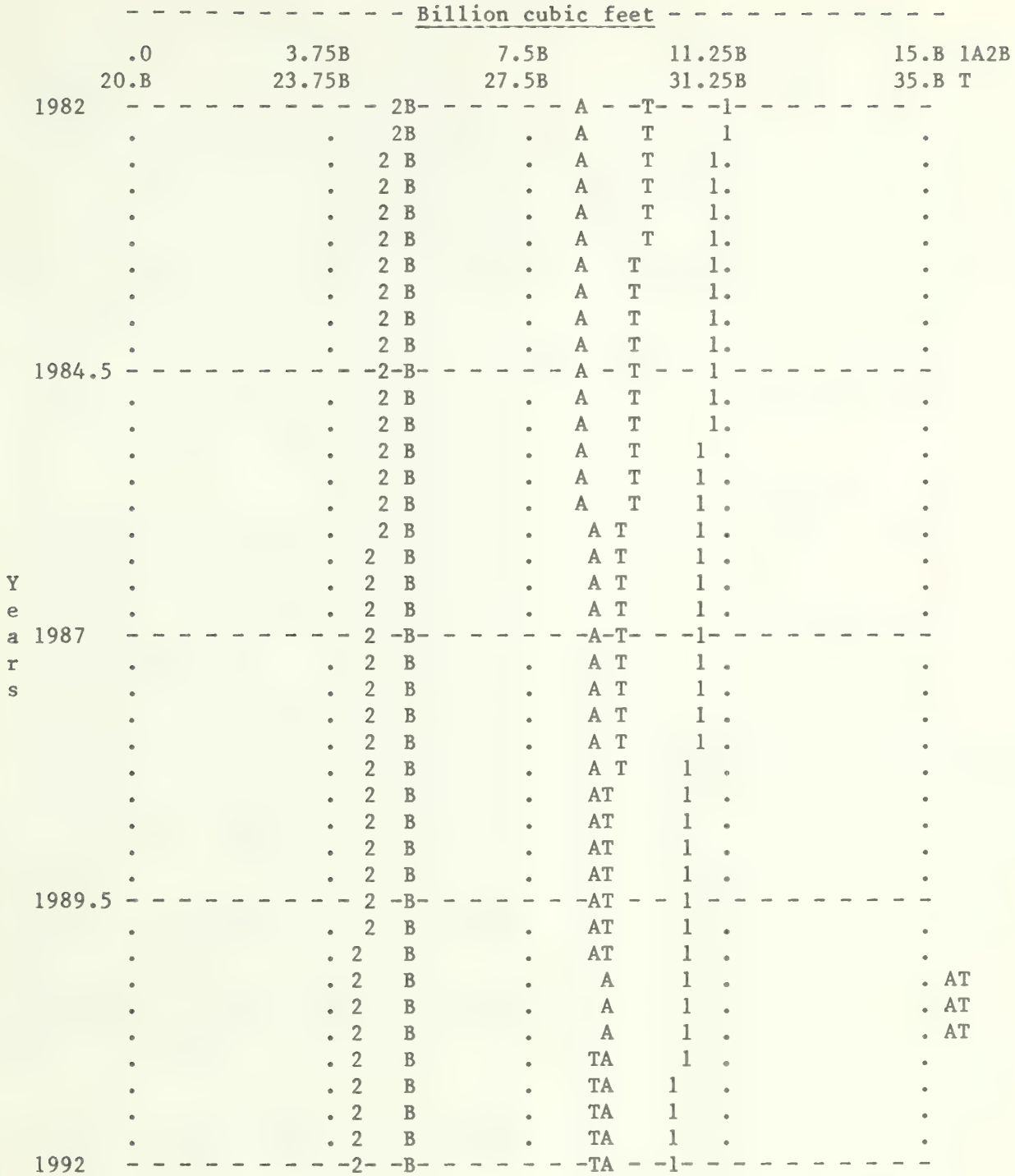

Figure 10.--DYNARIP base-run growing-stock-inventory volume projection, by broad species and size class, Georgia, 1982-1992. 1 = softwood sawtimber, 2 = softwood poletimber, A = hardwood sawtimber, B = hardwood poletimber, T = total.

Glossary

All live trees. All trees 1.0 inch d.b.h. and larger which are not dead at the time of inventory.

Broad forest type. A classification of forest land based on the species forming a plurality of live-tree stocking.

Hardwood forest type. Stands in which pines constitute less than 25 percent of live-tree stocking.

Oak-pine forest type. Stands in which pines account for at least 25 but not more than 50 percent of live-tree stocking.

Pine forest type. Stands in which pines constitute more than 50 percent of live-tree stocking.

Commercial species. Tree species conventionally regarded as being able to develop into trees suitable for the manufacture of industrial timber products. Species which typically exhibit small size, poor form, or inferior quality are excluded.

D.b.h. Tree diameter (outside bark) at breast height (4.5 feet above the ground).

Forest land. Land at least 16.7 percent stocked by forest trees of any size, or formerly having had such tree cover, and not currently developed for nonforest use.

Growing-stock trees. Live sawtimber-size trees of commercial species containing at least a 12-foot log, or two noncontiguous saw logs each 8 feet or longer, meeting minimum grade requirements (hardwoods must qualify as either a log grade 3 or 4; softwoods must qualify as a log grade 3) with at least one-third of the gross board-foot volume (International 1/4-inch rule) between a 1-foot stump and the minimum saw-log top being sound, or a live tree below sawtimber size that will prospectively qualify under the above standards.

Growing-stock volume. Volume (cubic feet) of solid wood in growing-stock trees 5.0 inches d.b.h. and larger, from a 1-foot stump to a minimum 4.0-inch top diameter, outside bark, on the central stem. Volume of solid wood in primary forks from the point of occurrence to a minimum 4.0-inch top diameter outside bark is included.

Hardwoods. Angiosperms; dicotyledonous trees (including all palm species which are monocotyledonous), usually broadleaf and deciduous.

Ingrowth. The number or net volume of trees that grow large enough during a specified year to qualify as saplings, poletimber, or sawtimber.

Level. The quantity of a given material at a particular instant in time.

Manageable stand. Commercial forest land at least 60 percent stocked with growing-stock trees that can be featured together under a management scheme.

Mortality. The merchantable volume in trees that have died from natural causes during a specified period.

Nonindustrial private forest (NIPF) lands. Forest land owned by farmers, individuals, or corporations; excluding forest industry land or land leased to forest industry.

Primary treatment or disturbance. The treatment or disturbance, man-caused or natural, in evidence as having occurred during the most recent remeasurement period and judged to have had the greatest influence toward creating the existing forest conditions.

Artificial regeneration after site preparation. The reestablishment of a timber stand by planting trees or direct seeding following site preparation on forest land that was harvested prior to the most recent remeasurement period.

Artificial regeneration on nonforest land. The establishment of a timber stand, at least 16.7 percent stocked with live trees, by planting trees or direct seeding on lands previously classed as nonforest.

Artificial regeneration without site preparation. The reestablishment of a timber stand by planting trees or direct seeding without site preparation of forest land harvested prior to the most recent remeasurement period. Includes artificial regeneration on forest sites prepared prior to the remeasurement period.

Cleaning, release, or other intermediate cutting. The act of freeing an immature stand of growing-stock trees from competition, by the mechanical removal of overstory trees and other inhibiting vegetation. Excludes prescribing burning, girdling, poisoning, and thinning.

Clearing or other site preparation. The mechanical removal of residual trees, inhibiting vegetation, and other physical obstacles, and/or chopping, raking, disking, and bedding to prepare the site for planting trees or direct seeding.

Commercial thinning. The removal of some of the merchantable trees from an immature stand to improve the growth and quality of the remaining trees. A sufficient stocking of growing-stock trees is left for a manageable stand.

Construction of fences, woods roads, firebreaks, trash pits, etc. The introduction of these or similar disturbances into a timber stand, if such activity has significantly influenced the stand condition.

Girdling or poisoning undesirable trees. The act of freeing an immature stand of growing-stock trees from competition by the killing or poisoning, but not felling, of poor-quality trees.

Grazing or other activity that retards or precludes development of the understory. Grazing of domestic livestock, repeated mowing, or any similar activity which inhibits the establishment and development of the understory trees within a forest condition.

Harvesting followed by artificial regeneration. The reduction of a merchantable stand of timber below a manageable level of stocking, and the subsequent reestablishment of a manageable stand of growing-stock trees by planting or direct seeding, either with or without site preparation.

Harvesting followed by natural regeneration. The reduction of a merchantable stand of timber below a manageable level of stocking, and the subsequent reestablishment of a manageable stand of growing-stock trees from advanced regeneration, natural seeding, or sprouting. Excludes conventional seed-tree method of harvesting.

Harvesting leaving seed trees, with satisfactory regeneration. The reduction of a merchantable stand of timber below a manageable level of stocking, but leaving a sufficient number of seed trees for regeneration as evidenced by the reestablishment of a manageable stand of growing-stock trees from the seed tree reproduction.

Harvesting leaving seed trees, without satisfactory regeneration. The reduction of a merchantable stand of timber below a manageable level of stocking, but leaving a number of seed trees for regeneration. A manageable stand of reproduction from the seed trees has not yet become established.

Harvesting without regeneration. The reduction of a merchantable stand of timber below a manageable level of stocking without leaving seed trees, and no manageable stand of natural reproduction exists.

Major drainage efforts. Construction of canals, ditches, or similar drainage efforts which permanently reduce the water table within the stand as evidenced by existing stand conditions.

Major man-caused flooding. Construction of dams, ponds, lakes, or similar activities which raise the water table within the stand as evidenced by existing stand conditions.

Natural regeneration on nonforest land. The establishment of a timber stand, at least 16.7 percent stocked with live trees, through natural reproduction on lands previously classed as nonforest.

No treatment or disturbance. Existing forest conditions exhibit no discernible evidence of any significant treatment or disturbance during the remeasurement period.

Other. Existing forest conditions exhibit evidence of a significant treatment or disturbance during the remeasurement period other than those described here.

Precommercial thinning. The mechanical removal or destruction of seedlings, saplings, or other small, unmerchantable trees from a young, overstocked stand to enhance the growth and dominance of the residual trees in a manageable stand.

Prescribed burning. The practice of using controlled fire to eliminate or reduce unincorporated organic matter on the forest floor or low, undesirable vegetation.

Removal of selected trees resulting in high grading. The removal of selected trees (usually the best or highest valued) from a merchantable stand of timber, but leaving sufficient stocking of residual trees for a manageable stand.

Salvage cut. The harvesting of a merchantable stand of recent mortality trees, or trees in imminent danger of mortality.

Significant damage from disease. Damage to a stand of timber severe enough to significantly reduce current or prospective growth, and caused by fungi, bacteria, rusts, blights, or other agents of disease.

Significant damage from insects. Damage to a stand of timber severe enough to significantly reduce current or prospective growth, and caused by the direct activity of insects.

Significant damage from weather and other natural destructive agents. Damage to a stand of timber severe enough to significantly reduce current or prospective growth, and caused by severe weather conditions such as high winds, freezing, ice storms, drought, flooding (other than man-caused), or damage associated with wildlife such as beaver.

Significant damage from wildfire. Damage to a stand of timber severe enough to significantly reduce current or prospective growth, and caused by uncontrolled fire.

Turpentining. The working of pine trees within a stand of timber for the commercial production naval stores.

Poletimber-size trees. All live trees at least 5.0 inches d.b.h., but smaller than sawtimber size.

Rotation age. The period of years required to grow a stand of timber to economic or natural maturity.

Saplings. Live trees 1.0 to 4.9 inches d.b.h.

Sawtimber-size trees. Softwoods 9.0 inches d.b.h. and larger and hardwoods 11.0 inches d.b.h. and larger.

Seedlings. Live trees of commercial species less than 1.0 inch d.b.h. that are expected to survive and develop.

Softwoods. Gymnosperms; in the order Coniferales, usually evergreen (includes the genus Taxodium which is deciduous), having needles or scalelike leaves.

Stand-size class. A classification of forest land based on the diameter class distribution of growing-stock trees in the stand.

Nonstocked stands. Forest land less than 16.7 percent stocked with growing-stock trees.

Poletimber stands. Stands at least 16.7 percent stocked with growing-stock trees of which half or more of total stocking is in poletimber and sawtimber trees, and with poletimber stocking exceeding that of sawtimber.

Sapling stands. Stands at least 16.7 percent stocked with growing-stock trees of which more than half of the total stocking is saplings and seedlings, and with sapling stocking at least equal to that of seedlings.

Sawtimber stands. Stands at least 16.7 percent stocked with growing-stock trees, with half or more of total stocking in sawtimber and poletimber trees, and with sawtimber stocking at least equal to poletimber stocking.

Seedling stands. Stands at least 16.7 percent stocked with growing-stock trees of which more than half of the total stocking is saplings and seedlings, and with seedling stocking exceeding that of saplings.

Stocking. The degree of occupancy of land by trees, measured by basal area or the number of trees in a stand, compared with a minimum standard required to fully utilize the growth potential of the land.

Timber removals. The merchantable volume of trees removed from the inventory by harvesting, cultural operations such as stand improvement, land clearing, or changes in land use.

Bechtold, William A.
DYNARIP: A technique for regional forest inventory projection and policy analysis. Res. Pap. SE-243. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1984. 43 p.

DYNARIP is a policy-oriented model capable of tracking all of the treatments and disturbances experienced by the forest resources of an entire State or regional area. It can also isolate the impact of any one of 27 man-caused or natural disturbances (including natural succession and forest land-base changes). The model is driven by empirical rates of change as measured by forest inventories between two points in time. A few simple controls permit the entry of the user's own perceptions of the future into the model.

KEYWORDS: Forest policy, forest simulation, forest inventory projection, resource evaluation, ecosystem dynamics.

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Research Paper
SE-244

The Pine Resource in South Carolina: an Interim Assessment, 1983

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John B. Tansey

Foreword

Since the mid-1930's, the U.S. Forest Service has monitored the Nation's forest resources by conducting periodic surveys State by State. The Forest Inventory and Analysis (FIA) Work Unit of the Southeastern Forest Experiment Station conducts these surveys in Florida, Georgia, North Carolina, South Carolina, and Virginia with assistance from the States, forest industries, and other forestry interests. These surveys, traditionally conducted on cycles of approximately 10 years, were previously completed in South Carolina in 1936, 1947, 1958, 1968, and 1978. Results of past surveys indicate this interval is sometimes too long to accurately monitor rapid changes such as those occurring in the pine timber resource in South Carolina in recent years. Reducing the interval between full-scale inventories is not practical when only a particular portion of the resource is of concern. An interim survey, customized to concentrate on a discrete resource problem or on a specific geographic area will often suffice. Interim surveys cannot and should not be expected to replace periodic full-scale inventories; they can provide vital updated information in a short period of time. This paper reports the findings of the recently completed interim survey of South Carolina's pine resource.

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Project Leader

April 1984

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The Pine Resource in South Carolina: an Interim Assessment, 1983

John B. Tansey

Forest Inventory and Analysis
Asheville, North Carolina

Abstract

Since 1978, the merchantable volume of all live yellow pine in South Carolina has declined by 22.7 million cubic feet, or by 0.3 percent. This relatively small change masks larger changes which occurred in each of three survey regions in the State. Yellow pine volume declined from 3.4 to 3.1 billion cubic feet in the Piedmont, increased from 3.0 to 3.2 billion cubic feet in the Northern Coastal Plain, and increased from 2.1 to 2.2 billion cubic feet in the Southern Coastal Plain.

Annual removals of pine timber have increased about 24 percent across all ownerships since 1977. The most significant increase was on NIPF land, where removals increased by 79.6 million cubic feet, or by 35 percent.

Net annual growth declined by 28 percent, due primarily to reductions in ingrowth and a slowdown in the annual radial increment of most of the major species in the State. These declines were particulary severe in the Piedmont.

Mortality increased by 15 percent Statewide; almost all of this increase occurred in the Piedmont where southern pine beetle outbreaks erupted in 1979 and 1980.

Between 1978 and 1983, only 4 of every 10 acres harvested were artificially regenerated. Forest industry regenerated 8 of every 10 acres harvested, while NIPF owners regenerated less than 1 of every 4.

Keywords: Annual radial increment, survivor growth, ingrowth, removals, mortality, southern pine.

Background

The fifth remeasurement of South Carolina's timberland in 1978 indicated that since 1968 the merchantable volume of yellow pine had increased 2.3 billion cubic feet, or by 36 percent, and that net growth in 1977 exceeded removals by 69 percent (Knight and McClure 1979). Between 1968 and 1978, net growth had increased by 203.4 million cubic feet, or by 49 percent, while removals had increased by only 84.0 million cubic feet, or by 30 percent. Although the forest resource situation looked encouraging in 1978, subsequent expansion of wood-using industries in the State was placing increased demands on South Carolina's pine timber. Further expansion would most likely aggrevate the situation. For this reason, an updated inventory of South Carolina's pine resource seemed worthwhile. Midcycle information can be of considerable planning value to many forestry related interests. Two previous interim surveys, one in South Carolina (Welch and Cathey 1976) and one in Virginia (Sheffield and Craver 1981) developed out of concern over changing resources. In early March 1983, a meeting was held to discuss the necessity of a similar midcycle update of South Carolina's forests. Participants, including representatives of the South Carolina Forestry Commission, forest industry, and FIA, agreed that an interim survey was needed.

The South Carolina Forestry Commission coordinated initial efforts to organize the survey. Training, conducted by FIA personnel at four locations in the State, began in mid-May and was completed by early June. Both FIA and the Forestry

Commission provided a field coordinator who were responsible for: (1) organizing field crews, (2) providing additional training, (3) check cruising, and (4) locating lost plots. Manpower and transportation were provided by both the Forestry Commission and forest industry. Fieldwork was completed in September and preliminary results were released at a combined meeting of Federal, State, and industry personnel in Columbia, S.C., in October.

The 1983 Interim Survey could not have been accomplished without the excellent cooperation of all participants involved. A list of all cooperators is provided at the end of this report.

Sampling Procedures

The primary objectives of the interim survey were to determine changes in pine timber volume since the previous regular inventory of South Carolina's forests in 1978 and to examine recent rates of pine regeneration in the State. Because the survey would only be concerned with yellow pine species, only those plots which had a pine on them in 1978, or those which would likely have pine ingrowth since 1978, would need to be visited. All plots installed during the fifth survey where a pine tree 1.0-inch d.b.h. or larger had been tallied were revisited. In addition, all plots where the presence of pine seedlings was formerly indicated were visited to check for the possibility of pine ingrowth. Upland hardwood sites and nonstocked forest land were assumed to have a high potential to develop pine ingrowth, and these samples were also visited. Finally, all samples that were classified as idle farmland in 1978 were checked for reversion to forest land and for the presence of pine ingrowth. FIA has 4,034 permanent forest sample plots located throughout South Carolina. The above-mentioned criteria for remeasurement reduced the number of sample locations to be visited during the interim survey to 3,675, representing an area of approximately 11.1 million acres of commercial forest (fig. 1).

To expedite the data collection and minimize costs, standard FIA sampling procedures were modified at each sample location to be revisited. The amount and variety of information collected at each plot were greatly abridged. County maps and aerial photographs available from the 1978 survey were used in the relocation of these sample plots. FIA sample plots in South Carolina are designed as a cluster of 10 points systematically spaced within the general confines of a circular acre. A basal area factor of 37.5 square feet per acre is used at each point to determine the limiting distance for sample trees 5.0 inches d.b.h. and larger. A fixed-radius plot of 6.8 feet (1/300 acre) around each of the first three points is used to sample sapling-size trees. After locating the 10-point cluster sample, a very simple procedure was used for remeasurement. On points 1, 2, and 3, all survivor pines were measured at d.b.h., and pine ingrowth of 1.0-inch d.b.h. or larger was measured on the fixed-radius plot. No attempt was made to obtain ingrowth mortality or ingrowth removal data. On all 10 points, trees that had been cut or died were accounted for and the period since removal or death was estimated. No tree information was recorded for surviving pines on points 4 to 10. New diameters were estimated using the diameter growth rates determined from the remeasurements on points 1, 2, and 3. All hardwood stems recorded on the sample record in 1978 were ignored. The area descriptive information collected was also kept to a minimum. Only three area classifications were assigned to each plot, reflecting what had occurred since 1978 based on conditions encountered at point 1. The first classification, land use trend, established if the plot was still in commercial forest. Second, a classification of cutting history was assigned to each plot to describe the type of cutting activity, if any, that had occurred since 1978. Finally, each plot was classified as to the type of pine regeneration evident, if any, since the last survey.

Limitations on Interim Data

Because of rounding discrepancies encountered in the processing of the interim data, certain values presented for the fifth survey in this report

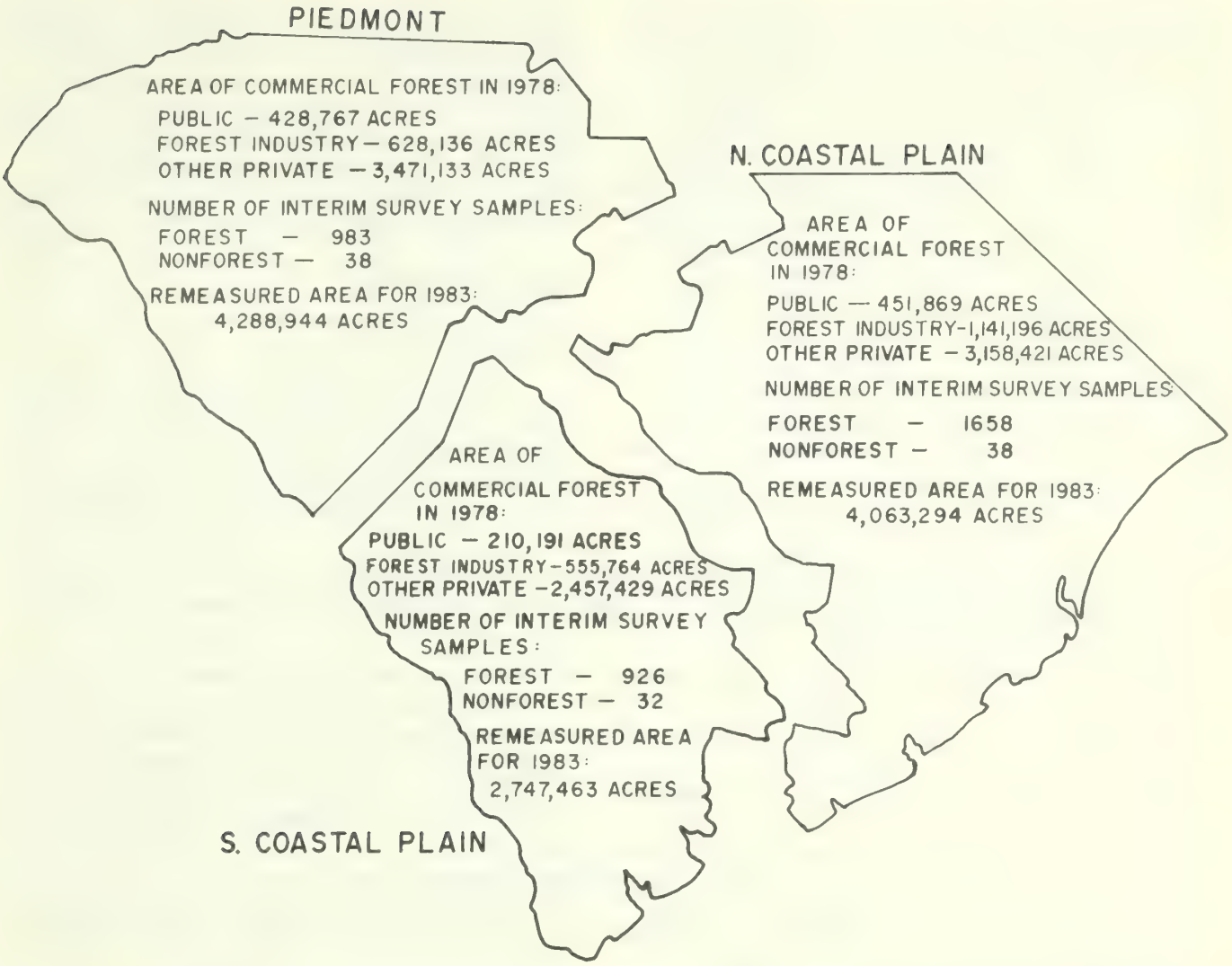

Figure 1.—Number of forest and nonforest samples remeasured, and area of commercial forest in 1978, by ownership, South Carolina interim survey, 1983.

differ slightly from previously reported values. These differences are extremely small. For instance, the 1978 yellow pine inventory reported here differs by only 0.02 percent from the 1978 volume reported in previous publications.

During the interim survey, no attempt was made to update certain area descriptive items used in this report. All distributions of acreage and volumes reported here, by ownership and broad management class, are based upon 1978 classifications. Without constant updating of these parameters, some discrepancy will occur between actual and reported values. In the 5 years since 1978, land transactions have occurred and ownership patterns may have changed somewhat. Changes in owner occupation also affect the acres of commercial forest in a particular ownership class. As tree diameters increase, as stands are thinned or harvested, and as species composition in a stand changes, broad management classes and stand sizes will also change. Also, no new estimates of total area of commercial forest land were made; all acreage figures presented are based on the 1978 area estimates.

Four hundred and sixty-seven plots considered as commercial forest in 1978 were not revisited during the interim survey because of the absence of pine on the sample acre. These plots, representing approximately 1.4 million acres of timberland, fell in hydric physiographic conditions such as deep swamps and cypress ponds or on mountainous physiographic sites. It is unlikely any of these sites experienced any artificial or

natural pine regeneration since 1978, but it is possible that some experienced a harvest or intermediate cut. For this reason, the acres of commercial forest reported as having received some treatment between 1978 and 1983 may be somewhat low. Comparisons between acres of timberland with a hardwood type harvested or disturbed during this time cannot be made with similar figures for the period between 1968 and 1978.

Estimates of annual removals, net growth, and mortality for the interim survey were computed by dividing total growth, mortality, and removals for the remeasurement period by the average length of the period. Interim estimates are not completely comparable with the 1978 averages because of slight differences in the methods used for arriving at annual estimates in a regular survey. However, as the change in inventory between two points in time becomes small, as is the case here, comparisons of growth, removals, and mortality using the two methods become more consistent.

Statewide Results

Yellow Pine Volume

Between 1978 and 1983 the merchantable yellow pine inventory in South Carolina declined by 0.3 percent, from 8,566.8[1] million cubic feet to 8,544.1 million cubic feet (table 1). During the

Table 1.--Change in merchantable volume of all live yellow pine timber on commercial forest land, by components of change and ownership class, South Carolina interim survey, 1978-1983

Item	All classes	Ownership class[a]			
		Public	Forest industry[b]	Other private	
				Farmer	Misc. private
	Thousand cubic feet				
Inventory 1978[c]	8,566,762	1,182,388	1,397,882	2,793,555	3,192,937
Period change:					
Gross growth	2,942,877	330,183	716,041	887,102	1,009,551
Mortality	480,660	60,991	68,076	166,300	185,293
Net growth	2,462,217	269,192	647,965	720,802	824,258
Removals	2,484,902	228,347	577,563	787,935	891,057
Net change	-22,685	40,845	70,402	-67,133	-66,799
Inventory 1983	8,544,077	1,223,233	1,468,284	2,726,422	3,126,138

[a] Ownership class as of 1978.

[b] Includes lands under long-term lease.

[c] Volumes reported for the fifth survey differ slightly from previously reported figures owing to rounding errors during interim survey processing.

[1] Volumes reported here may disagree slightly with previously reported fifth survey findings because of rounding discrepancies encountered in interim survey processing.

remeasurement period, net growth averaged 447.7 million cubic feet annually while removals averaged 451.8 million cubic feet annually. Average annual mortality amounted to 87.4 million cubic feet.

Pine volume increased by 3 percent on public land and by 5 percent on forest industry land. Pine volume on miscellaneous private and farmer-owned land decreased by 2 percent. Pine volume on public land accounted for 14 percent on the total pine inventory in both 1978 and 1983 (table 2). In 1978, pine volume on forest industry land accounted for 16 percent of the pine inventory and in 1983 accounted for 17 percent. Pine volume on NIPF (nonindustrial private forest) land, which includes farmer-owned land, other individual land, and other corporate land, accounted for 70 percent of the inventory in 1978 and 69 percent in 1983.

Volume of pine sawtimber increased by 5 percent and now totals 30.5 billion board feet (table 3). Although merchantable pine volume declined overall, all of this loss was confined to the 12-inch and smaller diameter classes. Merchantable pine volume in the 14-inch and larger diameter classes increased by 10 percent, which explains the sawtimber volume increase. Sawtimber volume increased on all ownerships except those of forest industry, where it declined by about 2 percent. Sawtimber volume increased by 7 percent on both public and miscellaneous private land and by 5 percent on farmer-owned land. NIPF land supplied about 76 percent of the sawtimber increase.

Loblolly, longleaf, slash, and Virginia pines increased in volume during the interim remeasurement period (fig. 2). The merchantable volume of loblolly pine increased by 3 percent and accounted for about two-thirds of the pine inventory in both 1978 and 1983. Loblolly supplied 71 percent of the increase in volume of the above-mentioned species. Virginia pine volume increased 14 percent, slash pine volume increased 4 percent, and longleaf volume remained about the same. The volumes of pond, shortleaf, pitch, and spruce pines declined. Shortleaf volume fell by 18 percent and accounted for 78 percent of the pine volume loss.

Losses of 10, 8, 6, and 3 percent occurred in the 6-, 8-, 10-, and 12-inch diameter classes, respectively (fig. 3). Declines in the poletimber-size classes account for 63 percent of the volume loss. Increases in volume occurred in each diameter class above the 12-inch class and ranged from 4 percent in the 14-inch class to 24 percent in the 21-inch and larger class.

Removals

Annual removals of pine timber have increased about 24 percent across all ownerships since 1977 (table 4). Estimates of annual net growth, mortality, and removals are assigned to a single year but actually represent an average for the entire remeasurement period. Thus, any annual fluctuations are not apparent. This increase in removals is

Table 2.--Distribution of inventory volume, net growth, mortality, and removals of merchantable yellow pine, by ownership class and year of inventory, South Carolina

Ownership class[a]	Inventory		Net growth		Mortality		Removals	
	1978	1983	1977	1982	1977	1982	1977	1982
	Percentage of total							
Public	14	14	11	11	18	13	12	9
Forest industry[b]	16	17	20	26	17	14	26	23
Other private	70	69	69	63	65	73	62	68

[a]Ownership as of 1978.

[b]Includes land under long-term lease.

Table 3.--Change in sawtimber volume of all live yellow pine timber on commercial forest land, by components of change and ownership class, South Carolina interim survey, 1978-1983

Item	All classes	Ownership class[a]			
		Public	Forest industry[b]	Other private	
				Farmer	Misc. private
	Thousand board feet				
Inventory 1978[c]	29,072,989	4,922,295	4,014,374	9,624,172	10,512,148
Period change:					
Gross growth	11,027,211	1,470,201	1,908,321	3,566,774	4,081,915
Mortality	1,066,925	208,017	114,413	349,666	394,829
Net growth	9,960,286	1,262,184	1,793,908	3,217,108	3,687,086
Removals	8,524,807	909,117	1,858,536	2,775,762	2,981,392
Net change	1,435,479	353,067	-64,628	441,346	705,694
Inventory 1983	30,508,468	5,275,362	3,949,746	10,065,518	11,217,842

[a]Ownership class as of 1978.

[b]Includes lands under long-term lease.

[c]Volumes reported for the fifth survey differ slightly from previously reported figures owing to rounding errors during interim survey processing.

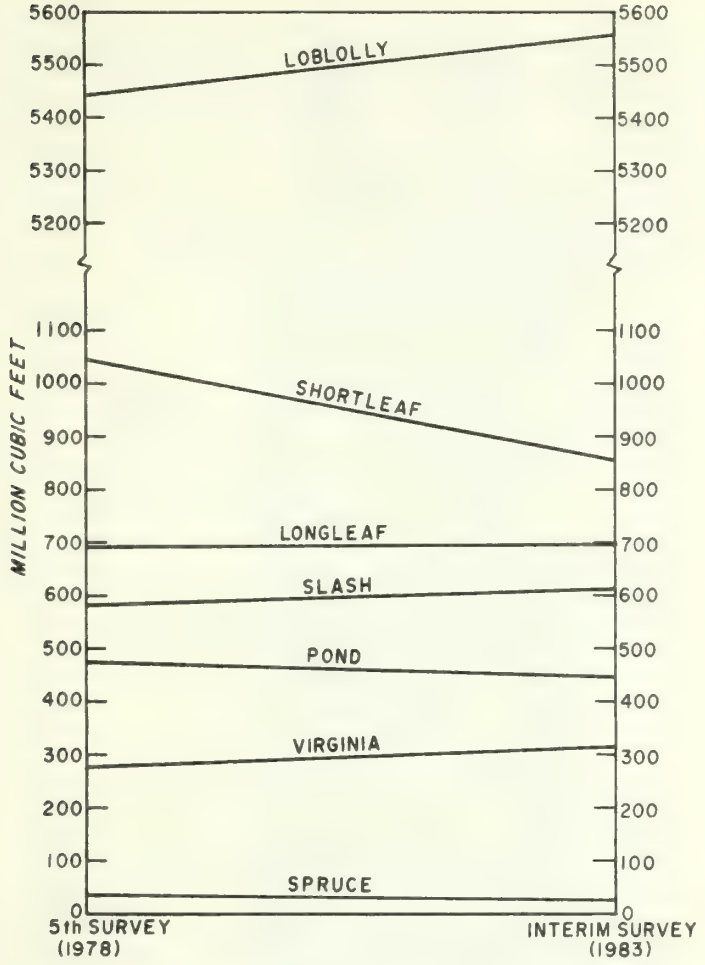

Figure 2.—Change in merchantable volume of all live yellow pine, by species, South Carolina interim survey, 1978 to 1983.

Figure 3.—Change in merchantable volume of all live yellow pine, by diameter class, South Carolina interim survey, 1978 to 1983.

substantiated by commodity drain studies, conducted annually in South Carolina that indicate the average annual softwood volume of industrial products output for the period between 1978 and 1983 has increased by 16 percent over the period between 1967 and 1977 (fig. 4). Removals increased by 11.1 million cubic feet, or by 12 percent, on forest industry land and by 79.6 million cubic feet, or by 35 percent, on other private land. On public timberland, removals declined by 3.5 million cubic feet, or by 8 percent, between 1977 and 1982. The distribution of removals among ownership classes changed slightly between survey periods (table 2). Public timberland supplied 12 percent of the removals in 1977, but only 9 percent during the interim period. Forest industry supplied 26 percent of the pine removals in 1977, slightly more than the 23 percent provided between 1978 and 1983. Other private land contributed a larger share of the removals in 1982, accounting for 62 percent of all removals in 1977 and 68 percent during the interim period. In 1977, net growth exceeded removals by 69 percent. Since then, the situation has changed drastically; in 1982, removals exceeded net growth by 1 percent. This reversal is due wholly to changes on other private land. In 1977, net growth exceeded removals by 88 percent on these lands; during the interim period, however, removals exceeded net growth by 9 percent.

Mortality

Annual mortality increased across all ownerships by 15 percent and totaled 87.4 million cubic feet in 1982 (table 4). Mortality on other private timberland equaled 63.9 million cubic feet, an increase of 30 percent. Mortality decreased on public timberland by 19 percent to 11.1 million cubic feet and by 5 percent on forest industry land to 12.4 million cubic feet.

Net Annual Growth

Net annual growth of pine timber has declined by 28 percent since 1977, from 617.5 million cubic feet to 447.7 million

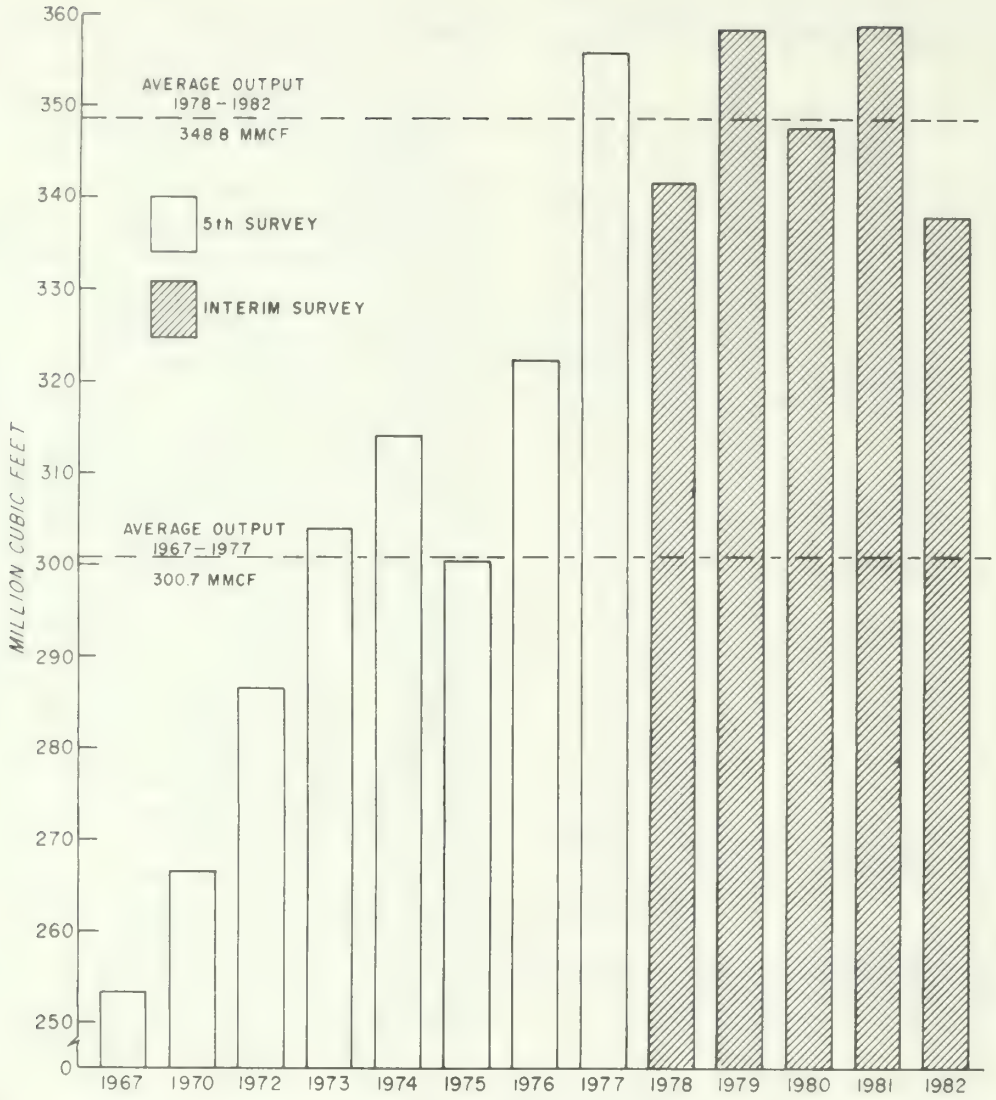

Figure 4. — Volume of softwood roundwood output of industrial timber products in South Carolina, 1967 to 1982.

cubic feet (table 4). Three factors contributed to this decline: increased mortality, less survivor growth (the volume increment on all live pines 5.0-inches d.b.h. and larger in the inventory at the beginning of the year and surviving to its end), and reduced ingrowth (the volume of all live trees reaching 5.0 inches d.b.h. during the year, and subsequent growth on these trees).

In 1977, annual mortality reduced gross growth across all ownerships by 11 percent. During the interim period, mortality reduced gross growth by 16 percent across all ownerships. On both public and other private land, mortality reduced gross growth by about 19 percent, while on forest industry land mortality reduced gross growth by 10 percent.

All live pines on points 1, 2, and 3 of each inventory sample were remeasured during the interim survey to arrive at diameter growth rates for the period between 1978 and 1983. A reduction in the average annual radial increment (AARI) of yellow pines during this time played a significant role in survivor growth decline in South Carolina. Across all merchantable-size diameter classes, the AARI of loblolly pine, the most abundant species in the State, declined by 10 percent from the period between 1968 and 1978 to the period between 1978 and 1983. During the same time, the AARI of shortleaf pine, the second most abundant species in the State, declined by 30 percent. These findings are consistent with results of recently completed surveys in

Table 4.--Net annual growth, annual mortality, and annual timber removals of merchantable yellow pine, by ownership class and year of inventory, South Carolina

Ownership class[a]	Net annual growth		Annual mortality		Annual timber removals	
	1977	1982	1977	1982	1977	1982
	Thousand cubic feet					
Public	66,720	48,944	13,709	11,089	45,047	41,518
Forest industry[b]	127,106	117,812	13,002	12,378	93,875	105,011
Other private	423,664	280,920	49,322	63,926	225,675	305,271
All classes	617,490	447,676	76,033	87,393	364,597	451,800

[a]Ownership class as of 1978.
[b]Includes land under long-term lease.

both Georgia and Alabama which show the AARI of southern yellow pines in these States also declining. This unexplained decline in radial increment of these and other pine species contributed to a 21 percent decline in the survivor growth of all live pines in South Carolina, from 570.2 million cubic feet per year in 1977 to 449.6 million cubic feet per year during the interim period (table 5). This decline in survivor growth accounted for 71 percent of the total decline in net growth between inventory periods.

Table 6 compares the pine inventory and components of change for the fifth survey with those of the interim survey using both new growth rates derived from remeasurements taken in 1983 and old growth rates derived during the fifth survey. If new growth coefficients had not been developed, growth for the interim period would have been overestimated. When the old growth coefficients were used in processing, net annual growth was shown to have declined by 18 percent, from 617.5 million cubic feet to 504.6 million cubic feet. However, using the new growth coefficients, net growth was shown to have actually declined by an additional 56.9 million cubic feet. Estimates of removal and mortality volumes were also affected by these changing growth rates.

The slowdown in radial increment is not the sole reason for growth declining between remeasurement periods. Between 1977 and 1982, ingrowth fell by 36 percent, from 109.9 million cubic feet to 70.2 million cubic feet (table 5). Reduced ingrowth accounted for another 23 percent of the total diminution in net growth and can be explained by comparing stand tables for the fifth and interim remeasurement periods.

Table 5.--Annual components of change in the merchantable volume of all live yellow pine on commercial forest land, by unit and survey, South Carolina

Unit and survey	Gross growth	Components of growth					Mortality	Net growth	Removals
		Survivor growth	Ingrowth	Growth on ingrowth	Growth on removals	Growth on mortality			
	Thousand cubic feet								
Unit 1:									
5th	189,475	154,651	27,042	4,112	3,117	553	14,462	175,013	98,151
Interim	147,459	125,655	15,492	2,204	3,597	511	16,764	130,695	122,061
Change	-22%	-19%	-43%	-46%	+15%	-8%	+16%	-25%	+24%
Unit 2:									
5th	222,959	189,814	24,531	3,885	3,660	1,069	29,569	193,390	135,567
Interim	207,235	173,876	24,132	3,729	4,824	674	20,584	186,651	156,732
Change	-7%	-8%	-2%	-4%	+32%	-37%	-30%	-3%	+16%
Unit 3:									
5th	281,089	225,760	44,445	5,914	3,923	1,047	32,002	249,087	130,879
Interim	180,375	150,097	22,683	1,929	4,543	1,123	50,045	130,330	173,007
Change	-36%	-34%	-49%	-67%	+16%	+7%	+56%	-48%	+32%
State:									
5th	693,523	570,225	96,018	13,911	10,700	2,669	76,033	617,490	364,597
Interim	535,069	449,628	62,307	7,862	12,964	2,308	87,393	447,676	451,800
Change	-23%	-21%	-35%	-43%	+21%	-14%	+15%	-28%	+24%

Table 6.--Comparison of merchantable yellow pine inventory and components of change between the fifth and interim surveys using old and new growth coefficients, South Carolina

Survey	Inventory	Components of growth		
		Net growth	Mortality	Removals
Fifth (MCF)	8,566,762[a]	617,490	76,033	364,597
Interim (New rates)	8,544,077	447,676	87,393	451,800
Percent Change	-0.3	-27.5	+14.9	+23.9
Interim (Old rates)	8,778,600	504,602	91,473	466,086
Percent Change	+2.5	-18.3	+20.3	+27.8

[a]Volumes reported for the fifth survey differ slightly from previously reported figures owing to rounding errors during interim survey processing.

Table 7.--Change in number of all live yellow pines on commercial forest land, by diameter class and survey, all ownerships, South Carolina

D.b.h. class	4th Survey	5th Survey	Percent change	Interim Survey	Percent change
	- - Million stems - -			Million stems	
2	1,344.8	993.9	-26.1	766.9	-22.8
4	748.6	605.2	-19.2	469.1	-22.5
6	359.5	377.8	+5.1	323.1	-14.5
8	172.6	238.1	+37.9	217.4	-8.7
10	95.7	135.2	+41.3	126.5	-6.4
12	54.4	76.5	+40.6	75.9	-.8
14	29.6	40.8	+37.8	42.4	+3.9
16+	28.0	38.2	+36.4	42.5	+11.3
Total	2,833.2	2,505.7	-11.6	2,063.8	-17.6

Number of Yellow Pines

Between 1969 and 1978, the number of 2- and 4-inch pines declined by about 26 and 19 percent, respectively (table 7). These declines were due to a reduction in the acres of young, natural pine stands becoming established on harvested commercial forest land and on nonforest land since the period between 1958 and 1968 and also to a reduction in the acres planted to pine since the Soil Bank era. In the 5 years between 1958 and 1962 alone, 40,000 more acres were planted to pine than during the entire 10-year period between 1969 and 1978.[2] Having a more serious effect on this diminution was the reduction in the establishment of natural pine stands, a trend that has continued since before 1950 and is evidenced in a 1978 stand-age profile of South Carolina's pine forest types (fig. 5). The acreage of natural pine forests established between 1958 and 1967 (ages 11 to 20) was only slightly more than half that established between 1948 and 1957 (ages 21 to 30), and the acreage established between 1968 and 1978 (00 to 10) was only 37 percent of that amount. What were declines in 2- and 4-inch pines have now moved across the merchantability threshold and into the 6-inch and larger diameter classes. During the fifth survey remeasurement period, the number of pines in the 6-inch diameter class had increased by 5 percent since the previous survey, also because of the high rate of planting in the late 1950's and early 1960's and because of the large acreage of natural pine forests established earlier. During the interim survey remeasurement period (which averaged 5.5 years as compared with normal cycles of about 10 years), the number of pines in the 6-inch class declined by 15 percent. This is one explanation for the reduction in ingrowth and suggests that further reductions in volumes in the larger diameter classes will occur in future years as fewer trees are available to progress upward through the stand table.

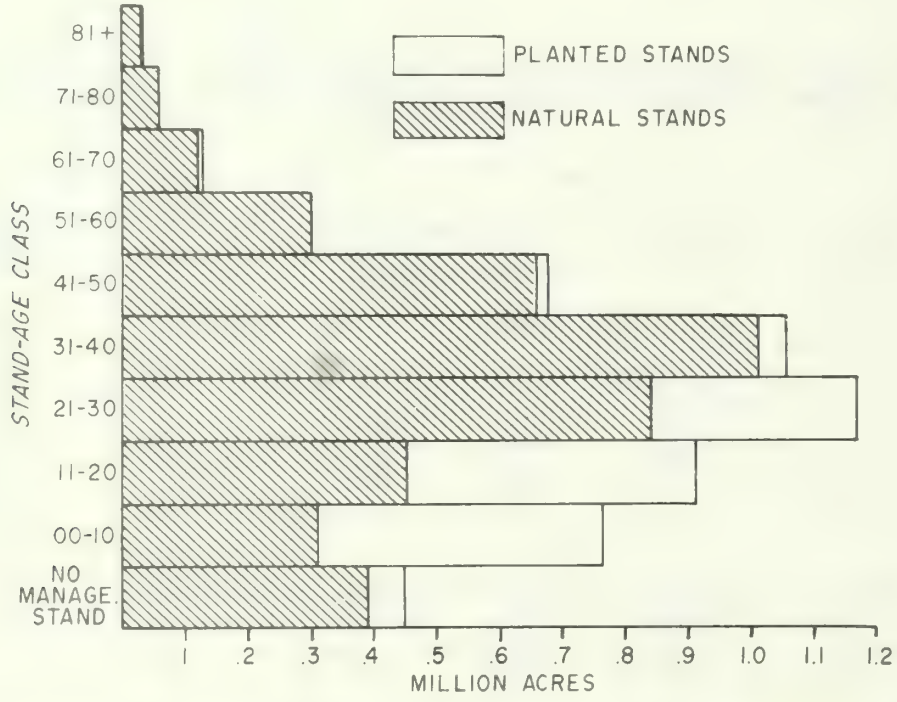

Figure 5. — Area of commercial forest land occupied by pine forest types, by stand-age class, all owners, South Carolina, 1978.

[2]Source: U.S. Department of Agriculture, Forest Service, U.S. Forest Planting Reports, 1958-1978.

All of the decline in 6-inch pines occurred on timberland in other private ownership. Here, the number of 6-inch pines fell by 26 percent (table 8). On forest industry and public land, the number of pines in this class increased by 11 and 16 percent, respectively. This is the result of the number of 4-inch trees on forest industry land remaining about the same between 1968 and 1978 and increasing by over 7 percent on public land. Across all ownerships, the number of 8- and 10-inch pines also declined, by 9 and 6 percent, respectively. One reason for the decline in poletimber and small sawtimber-size trees is the increased utilization for solid-wood products of smaller size material over the past 15 years. Also, round pulpwood production for the period between 1978 and 1982 increased 7 percent over the 5 previous years, placing increased demand on these smaller classes.

Since 1978, the number of 2- and 4-inch trees has declined by 23 percent in each class. This reduction occurred in all ownership categories and implies further reductions in ingrowth in the coming years. On forest industry land, the number of 2-inch pines declined by 22 percent and the number of 4-inch pines by 21 percent. Part of the explanation for this decline is the large acreage of natural pine being converted to plantations which have fewer stems per acre than natural stands. As of 1978 on forest industry land, 35 percent of the pine acreage in the 21 to 30-year age class, 82 percent in the 11 to 20-year age class, and 89 percent in the 00 to 10-year age class, was artificially established. On other private land, similar declines of 24 and 27 percent were seen. The number of 2- and 4-inch trees also declined on public land, but to a lesser degree, by 17 percent and by less than 1 percent, respectively.

Area Treated

Of the 6.4 million acres of commercial forest land remeasured in 1983 and classified as a pine or an oak-pine type in 1978, 32 percent, or 2.0 million acres, experienced some form of treatment between 1978 and 1983 (table 9). Harvested timberland accounted for 43 percent of the area treated. Since 1978, the rate of harvesting in pine and oak-pine types has increased from 102,600 acres annually to 160,200 acres annually, an increase of 56 percent. Intermediate or other cutting accounted for another 48 percent of the area treated. Forests often experience more than one treatment during any given period. Only the treatment that most affected the stand being sampled was noted during the interim survey. For this reason, the acreage of commercial forest assigned intermediate cutting as a past treatment may be somewhat low. Previously harvested or otherwise nonstocked forest land that was regenerated accounted for another 3 percent of the area treated. Almost 124,800 acres of commercial forest were diverted to other land uses.

Seven percent of the pine and oak-pine acreage harvested during the remeasurement period was in public ownership. About 67 percent of the total harvest occurred on NIPF land and about 26 percent occurred on forest industry land. In 1978, NIPF land owners controlled 69 percent of the commercial forest land in these types and forest industry controlled only 20 percent. Forest industry, as might be expected, provided a disproportionate share of the acreage harvested. Public and other private land experienced a higher percentage of intermediate and other cutting than did industry land. About 17 percent of all other private timberland and 16 percent of all public timberland with a pine or oak-pine type experienced some cutting other than final harvest since 1978, while just over 8 percent of forest industry land received any intermediate treatment.

About 92 percent of the pine and oak-pine forest diverted to other land uses was in NIPF ownership, 4 percent was publicly owned, and 4 percent was owned by forest industry.

Table 8.--Number of all live yellow pines on commercial forest land, by ownership class, survey, and diameter class, South Carolina

Ownership class[a] and survey	All classes	Diameter class							
		2	4	6	8	10	12	14	16+
	Thousand trees								
Public:									
5th	254,370	108,034	59,224	29,879	18,323	14,378	10,544	6,868	7,120
Interim	238,607	89,915	59,138	34,587	18,157	12,008	9,754	6,734	8,314
Forest industry:									
5th	548,631	210,676	155,930	87,356	49,472	23,117	11,736	5,862	4,482
Interim	488,499	164,376	123,938	96,714	58,068	24,760	10,581	5,433	4,629
Other private:									
5th	1,702,738	675,147	390,071	260,561	170,302	97,678	54,226	28,099	26,654
Interim	1,336,696	512,601	286,035	191,851	141,193	89,691	55,542	30,199	29,584
All classes:									
5th	2,505,739	993,857	605,225	377,796	238,097	135,173	76,506	40,829	38,256
Interim	2,063,802	766,892	469,111	323,152	217,418	126,459	75,877	42,366	42,527

[a]Ownership class as of 1978.

Table 9.--Area of commercial forest land with a pine or an oak-pine forest type treated or disturbed by recent stand history and ownership class, South Carolina interim survey, 1978-1983

Recent[a] stand history	All classes	Ownership class[b]		
		Public	Forest industry	Other private
	Acres[c]			
No significant treatment	4,357,769	507,183	959,003	2,891,583
Harvesting with artificial regeneration	284,498	29,686	155,883	98,929
Other harvesting[d]	596,519	33,067	75,362	488,090
Other cutting	973,443	106,681	108,935	757,827
Other artificial regeneration	5,161	--	5,161	--
Other natural regeneration	52,648	4,632	4,917	43,099
Diverted to other land use	124,777	5,479	4,461	114,837
Total	6,394,815	686,728	1,313,722	4,394,365

[a]Treatment experienced since 1978.

[b]Ownership class as of 1978.

[c]Acres based on 1978 expansion factors.

[d]Includes both harvesting with natural regeneration and harvesting without regeneration.

Looking at the entire 11.1 million acres of commercial forest remeasured during the interim survey, 1.3 million acres, or 12 percent, experienced harvesting between 1978 and 1983. Although the information on current stand history is not totally comparable with that from the last regular inventory, general trends in the annual rates of harvesting and regeneration can be established, remembering that the interim survey values may be slightly underestimated. Between the fifth and interim surveys, the annual rate of harvest increased from 196,700 acres to 233,500 acres. Almost all of this increase occurred on other private land, where the annual harvest increased from 123,300 acres to 158,200 acres. The annual harvest of commercial forest in public ownership increased slightly from 10,700 acres to 13,500 acres and on forest industry land declined from 62,800 to 61,800 acres. At the same time, the annual rate of artificial regeneration across all ownerships increased from 54,600 acres, or 28 percent of the acreage harvested during the fifth survey, to 93,800 acres, or 40 percent of the acreage harvested during the interim survey. This 72 percent increase is substantiated by U.S. Department of Agriculture, Forest Service annual planting reports which show the average annual acreage of both forest and nonforest lands planted between 1978 and 1982 exceeding that planted between 1968 and

1977 by about 85 percent. Although the annual rate of artificial regeneration increased in all ownerships, 63 percent of the increase occurred on NIPF land. Hopefully, with the initiation of the Forest Renewal Program in South Carolina in 1982, further increases in artificial regeneration rates will be seen in future years. As mentioned, 516,000 acres, or about 40 percent of the acres harvested, were artificially regenerated. This percentage varied widely by ownership and broad management class (table 10). NIPF timberland with natural pine types accounted for 49 percent of the harvest. Only 16 percent of these acres were artificially regenerated. Hardwood types accounted for only 18 percent of the harvest, but over 39 percent of this acreage was artificially regenerated. Pine plantations accounted for only 4 percent of the acres harvested on other private land. About 27 percent of the pine plantation harvest was artificially regenerated.

Across all broad management classes, forest industry artificially regenerated 8 of every 10 acres harvested. Natural pine types made up over half of the industry acreage harvested, and 71 percent of this area was artificially regenerated. Hardwood stands accounted for 15 percent of the harvested acreage and 78 percent of this area was artificially regenerated, confirming that forest industry continues conversion of many of its natural stands to plantations. Pine plantations made up approximately 11 percent of the harvest, and about three-fourths of this acreage was artificially regenerated. Public owners artificially regenerated about 1 of every 2 acres harvested. Natural pine stands accounted for 65 percent of the harvest, and 43 percent of these were artificially regenerated.

Regional Results

FIA has previously investigated the forest resources of South Carolina regionally, dividing the State into three survey units--the Piedmont, Northern Coastal Plain, and Southern Coastal Plain. Interim survey results differ significantly among these units. A brief summary of some of the more important findings for each of these areas follows:

Piedmont

In the Piedmont, the merchantable volume of all live pine declined from 3.4 billion cubic feet to 3.1 billion cubic feet since 1978. All of the net decline in pine volume in the State occurred in this region. Loblolly pine volume declined by 109.3 million cubic feet, or by 5 percent. Merchantable volume of shortleaf pine diminished by almost 19 percent to 731.7 million cubic feet. This reduction in volume accounted for 93 percent of the shortleaf decline Statewide.

Losses in the number of pine stems were larger here than in the State as a whole. Statewide, the number of 4-inch pines declined by almost 23 percent. In the Piedmont, the number of 4-inch pines declined by 96.9 million stems, or by 32 percent (table 11). At the State level, the number of pines in the 6-, 8-, and 10-inch classes declined by 14, 9, and 6 percent, respectively; they fell by 22, 20, and 13 percent in this unit.

Net annual growth decreased by 118.8 million cubic feet and accounted for almost 70 percent of the net growth reduction Statewide (table 5). Ingrowth fell from 50.4 million cubic feet to 24.6 million cubic feet annually. This 51 percent loss is well above the Statewide average decline of 36 percent. The AARI for the three most predominant species in the unit also declined significantly (fig. 6). The AARI across all diameter classes of loblolly and shortleaf pines, which together constitute 90 percent of the pine inventory in the Piedmont, slowed by 23 and 34 percent, respectively. The annual radial increment of Virginia pine decreased by 20 percent. These slowdowns had a significant effect on survivor growth, which declined by 34 percent. The drop in survivor growth accounted for three-fourths of the reduction in gross growth.

Mortality of merchantable pine increased 56 percent since 1977 and reduced potential net growth by 28 percent. Although no cause of death was recorded on inventory samples, it can be assumed that much of this increased mortality can be attributed to southern pine beetle infestations in 1979 and 1980 (Price and Doggett 1982) and more recently in 1982.

Table 10.--Acres of commercial forest land harvested and artificially regenerated by ownership and broad management classes, South Carolina interim survey, 1978-1983

Ownership class[a] and treatment[b]	All classes	Broad management class[c]				No manageable stand
		Pine plantation	Natural pine	Oak-pine	Hardwood	
	Acres					
Public:						
Harvest	74,478	11,477	48,479	2,797	9,243	2,482
Artificial regeneration	34,296	8,680	21,006	--	4,610	--
Percent of harvest	46.0	75.6	43.3	--	49.9	--
Forest industry:						
Harvest	339,763	36,232	171,246	23,767	51,837	56,681
Artificial regeneration	273,887	26,823	121,782	12,439	40,515	72,328
Percent of harvest	80.6	74.0	71.1	52.3	78.2	127.6
Other private:						
Harvest	869,971	32,410	421,977	132,632	154,734	128,218
Artificial regeneration	207,783	8,614	66,210	24,105	60,867	47,987
Percent of harvest	23.9	26.6	15.7	18.2	39.3	37.4
All owners:						
Harvest	1,284,212	80,119	641,702	159,196	215,814	187,381
Artificial regeneration	515,966	44,117	208,998	36,544	105,992	120,315
Percent of harvest	40.2	55.1	32.6	23.0	49.1	64.2

[a]Ownership class as of 1978.

[b]Treatment since 1978.

[c]Broad management class as of 1978.

Table 11.--Net change in number of all live pine trees on commercial forest land, by survey unit and diameter class, 1978-1983, South Carolina

Survey unit	All classes	Diameter class							
		2	4	6	8	10	12	14	16+
	Thousand trees								
Southern Coastal Plain:	-75,942	-38,970	-19,877	-14,751	-4,596	-802	498	1,510	1,046
Northern Coastal Plain:	-71,684	-59,951	-19,339	-85	7,315	202	-3,058	813	2,419
Piedmont:	-294,311	-128,044	-96,898	-39,808	-23,398	-8,114	1,931	-786	806

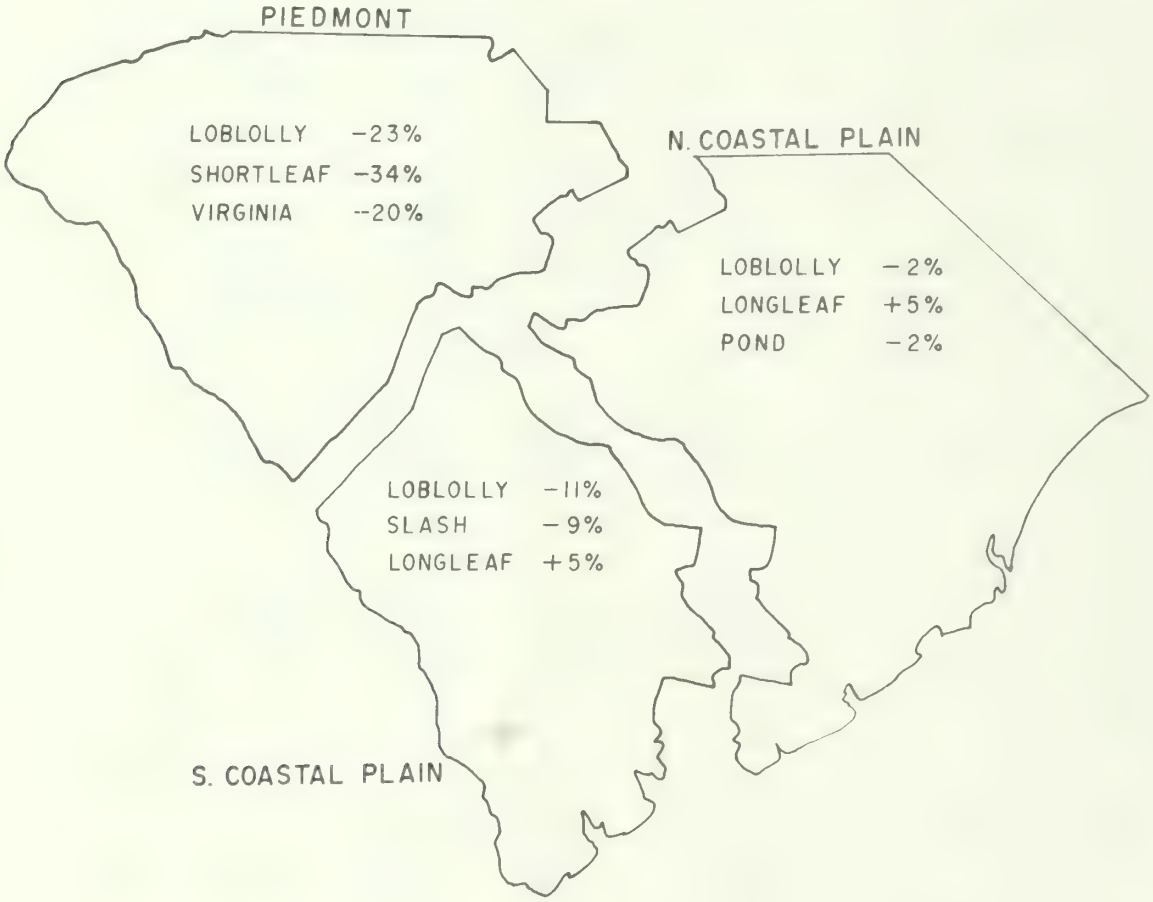

Figure 6. —Percent change in annual radial increment for selected species between fifth and interim surveys, South Carolina.

Removals increased by 32 percent since 1977, a much larger increase than the State average increase. Annual removals amounted to 173.0 million cubic feet during the interim survey and accounted for 38 percent of the State's total annual removal volume. Although not confirmed by data collected during the Survey, some of this increase in removals may be due to increased salvage cutting of pine stands which had been infested with southern pine beetles during the 1979 and 1980 outbreaks.

About 40 percent of the commercial forest land in South Carolina with a pine or an oak-pine forest type is located in the Piedmont, yet 47 percent of the acreage harvested in these types occurred in this unit.

Considering all types, 540,800 acres of the commercial forest land remeasured were harvested between 1978 and 1983, while 221,600 acres were artificially regenerated. This regeneration rate of 41 percent is slightly higher than the State rate.

Northern Coastal Plain

Merchantable pine volume increased by almost 6 percent in the Northern Coastal Plain to 3.2 billion cubic feet. Increases occurred in the volumes of loblolly, longleaf, and slash pines. Pond pine volume declined by 7 percent to 270.8 million cubic feet.

The number of pines in the 2-inch diameter class declined by 22 percent, about the same as the Statewide average. The number of pines in the 4-inch diameter class declined by 11 percent, considerably less than the State average. The number of pines in the 6-inch diameter class remained about the same and increased in all other merchantable-size classes except in the 12-inch class, where the number of pines declined by 12 percent.

Net annual growth decreased by 6.7 million cubic feet, or by 3 percent. Both survivor growth and ingrowth declined, but not by nearly as much as in the Piedmont and Southern Coastal Plain. Ingrowth dropped by 2 percent and survivor growth by 8 percent. The AARI of both loblolly and pond pines declined by 2 percent across all diameters. The AARI of longleaf pine increased by 5 percent.

Mortality of merchantable pine declined by 9.0 million cubic feet, or by 30 percent. In 1977, mortality reduced gross growth by 13 percent and during the interim period by only 10 percent.

Removals increased by only 21.2 million cubic feet to 156.7 million cubic feet. This increase was slightly less than that in the Southern Coastal Plain and only half of the increase in the Piedmont.

About 419,500 acres of the 4.1 million acres of commercial forest land remeasured were harvested between 1978 and 1983. At the same time, 144,700 acres, or 34 percent of the area harvested, were artificially regenerated.

Southern Coastal Plain

Merchantable pine volume increased by 49.4 million cubic feet, or by 2 percent, in the Southern Coastal Plain. The volume of loblolly pine increased by 8 percent. The volumes of longleaf, slash, pond, and shortleaf pines declined.

Reductions in the number of all live pines occurred through the 10-inch diameter class. The number of 2-inch trees declined by 23 percent and the number of 4-inch trees by 16 percent. Increases occurred in the 12-inch and above diameter classes.

Net annual growth dropped by 44.3 million cubic feet, or by 25 percent. A reduction in ingrowth of 13.5 million cubic feet accounted for almost one-third of the net growth loss. Survivor growth decreased by 29.0 million cubic feet. The AARI of both loblolly and slash pines declined by 11 and 9 percent, respectively. The AARI of longleaf pine increased by 5 percent.

Mortality increased by 16 percent to 16.8 million cubic feet during the interim period and reduced gross growth by 11 percent.

Between 1978 and 1983, almost 324,000 acres (12 percent of the commercial forest area remeasured in 1983) were harvested. Over 46 percent of these acres were artificially regenerated.

Discussion

Although Statewide merchantable pine volume declined slightly, all of this loss was confined to the Piedmont, where the pine inventory decreased by 245.5 million cubic feet. This decline was evident in all ownership classes. Pine volume increased by 49.4 million cubic feet in the Southern Coastal Plain and by 173.4 million cubic feet in the Northern Coastal Plain.

Net growth declined Statewide by 28 percent, but the reduction was more severe in the Piedmont. Loss of net growth on NIPF land in this region accounted for more than half of the overall decline in net growth in the State. Net growth increased only on forest industry land in the Northern Coastal Plain. Although no single explanation can be given for the significant reductions in survivor growth observed in most areas of the State, conditions such as the drought which existed between 1977 and 1981, singly or in conjunction with other environmental factors, no doubt had some adverse effect on tree growth during the interim survey period.

Mortality was most severe in the Piedmont, due primarily to southern pine beetle outbreaks in 1979 and 1980. More than likely, many pine stands in the Piedmont were unduly stressed by the aforementioned drought and therefore predisposed to southern pine beetle infestation. Mortality increased by 56 percent here and by 16 percent in the Southern Coastal Plain; it declined by 30 percent in the Northern Coastal Plain.

Although a major economic recession occurred during the period covered by the interim survey, average annual removals still increased compared with the period between 1967 and 1978; by 24 percent in the Southern Coastal Plain, by 16 percent in the Northern Coastal Plain, and by 32 percent in the Piedmont.

The numbers of 2- and 4-inch pines continued a declining trend in the period between 1978 and 1983. This situation must be curtailed if satisfactory ingrowth and subsequent volume in the larger diameter classes are to be expected in future years. Already, losses in the number of pine stems since the previous survey exist through the 12-inch diameter class. This problem must be resolved if South Carolina's growing forest-products industry is to be adequately supplied with raw materials in the coming decades.

Between 1978 and 1983, about 1.5 million acres of commercial forest land were either harvested or diverted to other land uses, while only 819,200 acres of commercial forest and nonforest land were regenerated, either naturally or by artificial means. About 23 percent of the commercial forests harvested or diverted and 37 percent of the area regenerated was in forest industry ownership. On forest industry land, more than 8 of every 10 acres harvested or cleared were regenerated. NIPF land accounted for almost 72 percent of the harvested or cleared commercial forest area but for only 57 percent of the regenerated lands. Other private owners regenerated less than half of the acres harvested or diverted. Hopefully, with the help of Federal and State incentives and educational programs, these acreages will come into balance in the future.

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The pine resource in South Carolina: an interim assessment, 1983. Res. Pap. SE-244. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1984. 22 p.

Between 1978 and 1983 southern yellow pine volume in South Carolina declined by 22.7 million cubic feet. Pine volume declined by 9 percent in the Piedmont, but increased by 6 percent in the Northern Coastal Plain, and by 2 percent in the Southern Coastal Plain. Annual removals of pine timber increased about 24 percent since 1977, while net annual growth declined by 28 percent. Annual mortality increased to 87.4 million cubic feet and in 1982 reduced gross growth by 16 percent.

KEYWORDS: Annual radial increment, survivor growth, ingrowth, removals, mortality, southern pine.

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KEYWORDS: Annual radial increment, survivor growth, ingrowth, removals, mortality, southern pine.

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Experiment Station

Empirical Yields of Timber and Forest Biomass in the Southeast

Research Paper
SE-245

Joe P. McClure

Herbert A. Knight

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Empirical Yields of Timber and Forest Biomass in the Southeast

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Forest Inventory and Analysis in the Southeast
Asheville, North Carolina

ABSTRACT

Measurements and classifications recorded at 24,775 Forest Survey plots established randomly throughout the Southeast comprise a vast source of information on timber stand development. Empirical yield tables developed from this source are reported for major forest types in the Region. These tables also serve as guides to yields of forest biomass by tree size and species groups.

Keywords: Southeast, yield tables, forest biomass.

Introduction

This Paper contains yield tables that show stand structure and development on Forest Survey plots in major forest types in the Southeastern States of Florida, Georgia, North Carolina, South Carolina, and Virginia. These yield tables were developed empirically from the average conditions observed on selected plots. In selecting the samples for construction of these yield tables, we screened measurements and classifications recorded at 24,775 Forest Survey plots established randomly throughout the Region. Only plots in timber stands classed as fully stocked by Forest Survey standards were used. The average yields shown represent a broader range of stocking and sites than is conventionally used in constructing yield tables, but they are reasonable guides to proven stand performance. These tables fill many of the voids in existing information on timber yields in the Southeast. In addition, they include the first comprehensive guides to yields in the Region expresse in terms of forest biomass.

Methods

Any good sample plot data may be used in the construction of empirical yield tables (Spurr 1952). Yield table construction requires an adequate sample from a specific forest type within the area or region to be served by the table. In general, stands are suitable for sampling when there are no recognizable factors measurably affecting growth other than those being evaluated: age, site, and stand density (Bennett 1966). Since the purpose of a yield table is to est mate productive potential rather than production based purely on stand history, the ideal method is to periodically measure carefully selected stands over the span of their development. This method is a slow, meticulous process that discourages yield table construction. We have attempted to use Forest Survey sample plots in the Southeast to shortcut the conventional method without violating acceptable standards.

In recent years, several mensurationists and resource analysts have probed the use of Forest Survey data to construct empirical yield tables (Cost and McClure 1982; Essex and Hahn 1976; Hahn and Raile 1982; Knight 1978; Knight and McClure 1981; Knight and Sheffield 1980). Although Forest Survey plots are neither designed nor intended for this purpose, they comprise a vast source of information on stand development across the full range of forest sites and conditions. Over the years, Forest Survey in the Southeast altered its procedures to accommodate this kind of use.

Field guides document the establishment and measurement of the Forest Survey samples plots used in this study. A copy of "Field Instructions for the Southeast, 1982" is available upon request. These field instructions also define the forest types included in this Paper.

Stand Age

Stand age is one of the key data elements required for sample plots used to construct yield tables. Prior to 1963, Forest Survey in the Southeast did not collect stand age on its sample plots. Instead, it used stand-size classes--seedling-sapling, poletimber, and sawtimber--to monitor and describe stand development. Although Forest Survey added stand age in 1963, it was applied and recorded in 10-year classes. Furthermore, the 10-point-cluster sample plot used at the time was allowed to straddle two or more distinct stands.

Forest Survey in the Southeast corrected both of these deficiencies in 1973 at the start of the fourth inventory of North Carolina (Knight and McClure 1975). Since then, to the extent possible, stand age has been determined to the nearest year and the cluster sample plot has been confined to a single stand as identified by point 1. These changes opened up the opportunity to use Forest Survey plots in the Southeast to construct empirical yield tables.

Generally, timber stands in the Region are even-aged. Although many of the stands have been high-graded from time to time, there is very little true selection cutting practiced in the Region. The origin of most stands can be traced to regeneration following a final harvest, some natural disturbance, or the reversion of agricultural land to forest. Although the stands are perceived and described as even-aged, many of the young stands contain a scattering of older, residual trees from a former stand and some of the older stands contain significant numbers of understory trees and pockets of advance reproduction. Crews record the age of the most prevalent stand. The stand age specified in these yield tables is the midpoint of a 5-year class. For example, the 10-year age class includes stands 8 through 12 years of age.

Site

Site is another key factor affecting timber yields. Forest Survey uses the height and age of a dominant tree, representative of the prevalent species in a stand, as an indicator of potential timber yield. Forest Survey groups these sites into productivity classes, expressed in cubic feet of growth per acre, for fully stocked natural stands at culmination of mean annual increment. Each of these site classes spans a wide range of site indexes. In this Paper, high sites include all sites capable of growing 85 cubic feet or more per acre; medium sites, 50 to 85 cubic feet; and low sites, 20 to 50 cubic feet. Where a comparative range of site indexes is indicated, height at age 50 is the base for both planted and natural stands.

In this Paper, the yield tables are for high sites, medium sites, or all sites. Low sites account for less than 20 percent of the commercial forest land in the Region, and fully stocked stands occupy only a portion of these low sites. For most forest types, the sample of fully stocked stands on low sites is too small to consturct yield tables.

Density

Density is another critical variable in empirical yield tables. In this Paper, the yield tables represent fully stocked stands measured against the Forest Survey stocking standard applied in the Region. This stocking standard is summarized below and is also included in each of the conventional Resource Bulletins (Tansey 1983).

In the measurement and classification of the sample plots, crews tallied overtopped trees but these trees were not permitted to

Stocking Standard

D.b.h. class (inches)	Minimum number of trees per acre for full stocking	Minimum basal area (ft^2) per acre for full stocking
Seedling	600	--
2	560	--
4	460	--
6	340	67
8	240	84
10	155	85
12	115	90
14	90	96
16	72	101
18	60	106
20	51	111

contribute to stocking. In screening out the plots used to construct these yield tables, the authors did not permit seedlings to contribute to the required stocking in stands 18 years or older. Saplings in the intermediate crown class were not permitted to contribute to the stocking requirement in any stand. In pine forest types, the stocking requirement had to be satisfied by yellow pine species. In hardwood types, all species were allowed to contribute to the stocking requirement. For all types, the stocking requirement had to be satisfied with growing stock; the stocking of rough and rotten trees was excluded.

Merchantability Standards

By precisely defining our merchantability standards, we hope to avoid a weakness common in many existing yield tables. In our tables, all volumes expressed in cubic feet are solid wood; they exclude bark and all rotten and missing wood detected in the trees. The total aboveground volume includes all solid wood above the ground line in all live trees 1.0 inch in diameter and larger at breast height (d.b.h.), excluding the volume in twigs and lateral limbs smaller than 0.5 inch in diameter.

Volume of growing stock is the solid wood in the central stem and forks of all growing-stock trees 5.0 inches d.b.h. and larger from a 1-foot stump to a minimum 4.0-inch top diameter outside bark (d.o.b.). Growing-stock trees are live trees of commercial species that meet specified standards for sawtimber or will likely meet such standards when they reach minimum sawtimber size--9.0 inches d.b.h. for softwoods and 11.0 inches d.b.h. for hardwoods. Volume in the sawlog portion of sawtimber trees is the solid wood from a 1-foot stump to a minimum 7.0-inch top d.o.b. for softwoods and a minimum 9.0-inch top d.o.b. for hardwoods. This sawtimber volume is expressed in net board feet, based on the International 1/4-inch log rule. The technique used to measure standing trees for developing volume-prediction equations for tree species in the Southeast is documented and available upon request (Cost 1978).

In these tables, we define forest biomass as the green weight of aboveground wood and bark (excluding foliage) in all live trees 1.0 inch d.b.h. and larger. Foliage includes leaves, needles, buds, fruit, twigs, and lateral limbs smaller than 0.5 inch in diameter. Studies by the Utilization of Southern Timber Research Work Unit at the Forestry Sciences Laboratory in Athens, Ga., provided the vital linkage between volume and weight (Clark 1979; McClure and others 1981; Saucier 1979).

Screening

To construct these empirical yield tables, we developed special summary records for each of the 24,775 sample plots on commercial forests in the Southeast. These plot summaries include 20 screening variables, ranging from location to stocking. Next, we wrote a special computer program for screening and compiling these plot summaries into specified groupings. This computer program selects or excludes individual plot records using any specified combination of the 20 screening variables. The tables in this Paper are part of the output from the computer program.

Discussion

We tried to validate the empirical yield tables developed from Forest Survey plot data by comparing them with other published information on yields. We reviewed numerous yield table studies and carefully examined the procedures used and the published results. In most cases, valid comparisons were impossible because of significant differences either in the procedures used or in the way the results were presented.

We established the following criteria for selecting an existing yield table for comparison: (1) the table should be based on a large sample of a well-defined forest condition over a broad geographic area, (2) the independent variables used in the table should be age, site, and stocking, (3) one or more of the units of measure should be comparable, and (4) the merchantability standards should be essentially the same as ours. With these criteria, the choice boiled down to the tables published by Schumacher and Coile (1960). From the host of yellow pine species contained in the Schumacher and Coile publication, we selected loblolly pine because it had the widest geographic range and a sample of 420 plots.

Although a few differences exist between the two data sets, these differences are small and could easily compensate for one another. For example, Schumacher and Coile estimated the cubic-foot volume of the

entire tree stem (inside bark) based on the height of dominant stand and 1.0-inch diameter classes. We computed the total aboveground cubic volume of sample trees individually using total height and actual d.b.h. Another minor difference between the two data sets involves the selection of the sample plots. Schumacher and Coile purposely selected even-aged stands judged to be well stocked, undisturbed by past cutting, and representative of a homogeneous site. The Forest Survey sample differs in that all plots used in a specific yield table were selected from the regionwide summary records by sequentially screening each plot through specific type, site, age, and stocking criteria.

Table 1 compares our results with those of Schumacher and Coile for natural loblolly pine stands in the Coastal Plain of the Southeast. From Schumacher and Coile, the cubic volume for the entire stand (inside bark, stump to tip) for site index 70 was compared with Forest Survey's total aboveground volume of southern yellow pine. Since the yields published by Schumacher and Coile apparently excluded all hardwood volume encountered on the sample plots, any hardwood volume was excluded from the Forest Survey yields for the comparison. Since 100 percent or more stocking of southern yellow pine was required in the Forest Survey samples, any hardwood volume would likely be in small trees of tolerant species in the understory.

In the comparison, we first plotted the Schumacher and Coile yields for site index 70 over stand age and drew a freehand curve through the plotted points to establish a reference curve between 5 and 85 years of age. Next, we plotted the Forest Survey yields averaged by 5-year age classes and noted the number of samples in each average. Displayed in this manner (fig. 1), it is obvious the Schumacher and Coile curve is well within the central area of the plotted points throughout the range of the data.

This comparison leads the authors to conclude that Forest Survey data compare favorably with the highly respected yields developed by Schumacher and Coile. Since the

Table 1.--Comparison of yields for well-stocked, natural stands of loblolly pine on medium sites[a] in the coastal plain of the Southeast

Stand age (years)	Schumacher and Coile (entire stand)	Forest Survey (total aboveground)			Number of plots
		Yellow pines	All species		
			Volume	Standard error	
	Cubic feet per acre				
5	--	77	78	40	13
10	--	717	773	155	10
15	--	1,254	1,479	137	20
20	1,690	1,694	2,014	83	40
25	--	2,311	2,636	128	25
30	2,540	2,452	2,795	82	43
35	--	2,659	3,160	153	30
40	3,100	2,714	3,148	139	29
45	--	3,018	3,361	102	22
50	3,460	3,636	4,227	181	14
55	--	3,270	3,643	264	6
60	3,720	3,367	3,966	451	5
65	--	5,351	6,286	--	1
70	3,910	4,060	4,682	--	1
75	--	3,591	4,079	205	3
80	4,050	2,763	3,074	247	3
85	--	4,295	5,754	--	1

[a]Schumacher and Coile, Site Index 70; Forest Survey, Site Class 4 (Site Index 60-78).

other empirical yields presented in this Paper were developed by using methods similar to those used for loblolly pine, the entire series should compare favorably when fairly tested against the results of other, good yield studies.

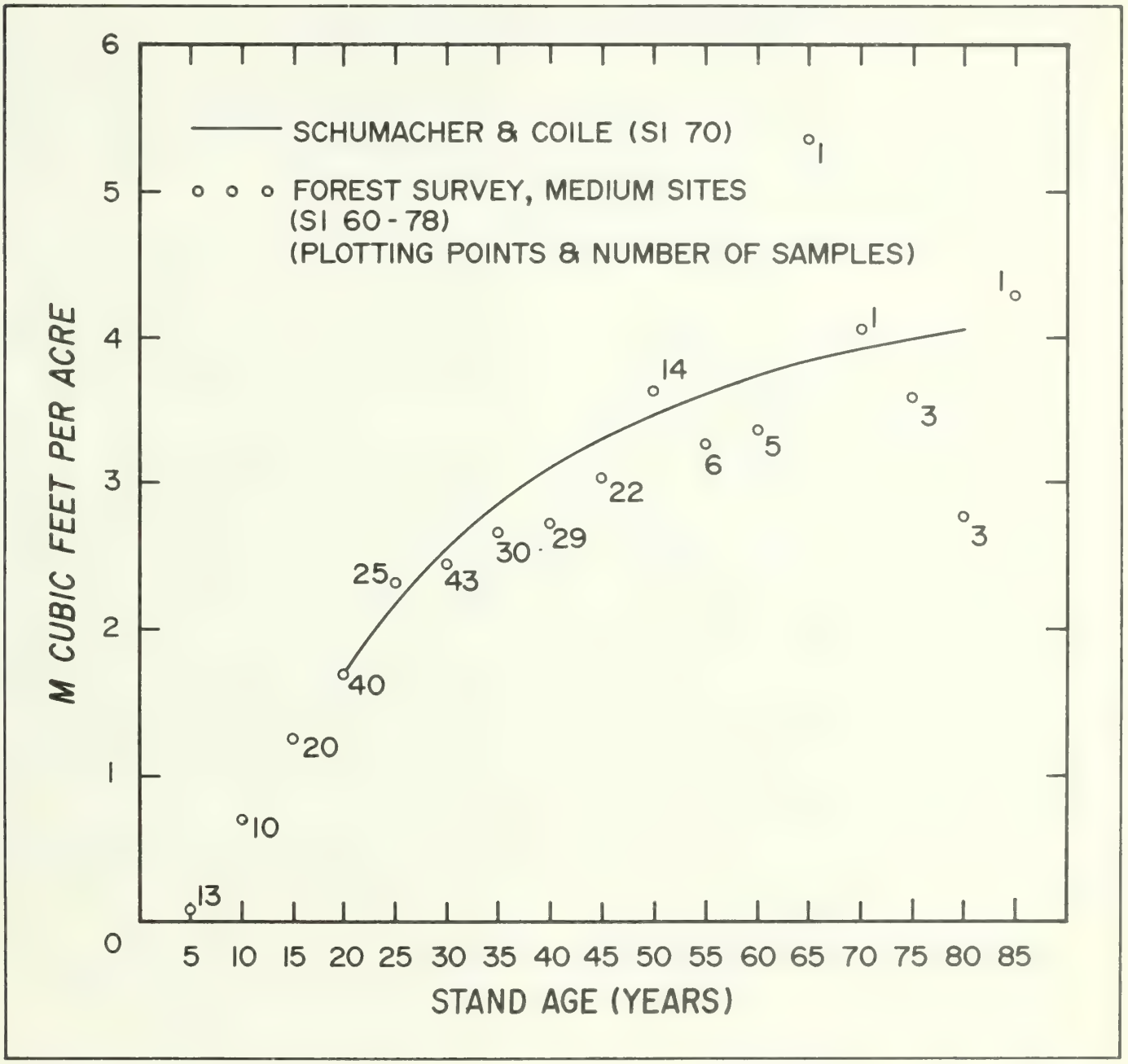

Figure 1.--Yields for fully stocked natural loblolly stands on medium sites in the Coastal Plain of the Southeast.

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Yield Tables for Fully Stocked Stands

Tables 1a, 2a, 3a, ... 34a show the average empirical yields of timber expressed in numbers of trees, basal area, and volumes per acre for fully stocked stands for specific timber types, sites, and regions, by 5-year age classes.

Table 1b, 2b, 3b, ... 34b are companion tables which show the average empirical yields of forest biomass expressed in green tons per acre, by tree size and species group.

Table 1a.--Average empirical yields of timber for fully stocked stands

Type: Natural loblolly pine **Site:** Medium (SI 60-78) **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
		1.0+	5.0+	9.0+	13.0+	17.0+		Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
											Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	23	1,391	82	--	--	--	16	744	107	186	--	--
15	39	1,417	202	19	--	--	53	1,495	117	709	110	581
20	70	1,567	257	29	3	--	70	1,968	78	1,065	257	1,368
25	56	1,142	308	49	7	1	95	2,497	79	1,586	567	3,005
30	77	1,036	294	75	11	1	106	2,739	69	1,927	882	4,677
35	62	1,131	286	80	14	1	107	2,947	115	2,090	1,042	5,519
40	55	882	253	95	19	2	110	3,124	105	2,326	1,407	7,459
45	44	947	236	93	24	3	109	3,217	110	2,422	1,602	8,484
50	17	1,083	214	116	39	8	124	4,043	180	3,163	2,509	13,279
55	12	965	198	100	35	7	113	3,556	181	2,815	2,174	11,519
60	11	1,011	217	96	34	8	114	3,468	298	2,610	2,054	10,877
65	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 1b.--Average empirical yields of forest biomass for fully stocked stands

Type: Natural loblolly pine **Site:** Medium (SI 60-78) **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	26.4	3.7	10.1	--	--	--	23.3	--	1.1	1.0	0.9	0.2
15	54.4	4.2	35.6	7.6	--	--	48.3	--	2.7	1.2	1.9	.3
20	72.3	2.9	51.8	15.8	3.3	--	61.9	0.1	3.8	1.9	3.5	1.1
25	91.5	2.9	75.4	30.5	9.8	3.4	81.6	.3	4.4	1.8	2.8	.7
30	101.1	2.6	89.1	48.2	13.9	3.1	88.8	.4	4.8	3.0	2.6	1.5
35	109.0	4.3	95.8	56.1	17.3	2.2	93.3	.1	5.4	3.6	4.0	2.5
40	115.5	3.9	104.7	73.7	25.8	5.5	99.0	.5	5.7	2.7	5.1	2.5
45	118.5	4.0	107.3	79.4	34.1	7.1	104.1	.6	5.4	2.9	4.0	1.5
50	149.1	6.5	136.4	117.7	62.8	18.6	126.7	--	9.2	7.1	3.5	2.7
55	130.9	6.9	121.0	101.3	54.5	15.2	117.2	.4	5.2	3.4	3.7	.9
60	129.0	11.0	116.2	94.9	54.2	18.5	107.4	.5	2.2	4.3	7.9	6.6
65	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 2a.--Average emprical yields of timber for fully stocked stands

Type: Natural loblolly pine **Site:** High (SI 79+) **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
								Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
		1.0+	5.0+	9.0+	13.0+	17.0+					Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	8	995	185	6	--	--	40	969	245	447	46	246
15	9	1,620	216	26	3	--	61	1,889	382	1,031	279	1,474
20	22	841	285	74	13	2	106	2,762	189	1,994	993	5,251
25	61	857	274	84	17	3	112	2,975	90	2,210	1,196	6,341
30	87	927	292	106	25	4	128	3,633	92	2,790	1,696	8,980
35	71	816	251	121	33	5	131	3,954	113	3,114	2,222	11,768
40	65	788	237	116	41	7	133	4,305	131	3,403	2,601	13,795
45	36	724	221	117	52	11	137	4,581	173	3,711	3,026	16,055
50	26	728	197	118	59	13	138	4,809	209	3,954	3,420	18,155
55	14	692	234	128	50	9	142	4,514	330	3,431	2,805	14,886
60	5	950	174	97	49	12	120	4,159	341	3,273	2,937	15,593
65	7	690	176	122	73	23	154	5,588	480	4,616	4,410	23,415
70	3	804	171	103	57	13	126	4,323	563	3,526	3,178	16,877
75	2	727	157	128	67	14	146	5,330	20	4,097	4,020	21,253
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 2b.--Average empirical yields of forest biomass for fully stocked stands

Type: Natural loblolly pine **Site:** High (SI 79+) **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	35.3	9.2	23.6	3.1	--	--	31.8	--	1.8	0.1	1.2	0.4
15	68.3	14.0	48.6	15.5	4.7	--	64.6	--	2.7	.7	0.2	.1
20	102.0	7.1	92.4	51.2	17.8	6.1	94.9	0.1	4.6	.5	1.6	.3
25	110.1	3.3	100.5	62.7	23.1	6.2	97.1	.2	3.9	3.9	4.2	.7
30	134.6	3.4	124.2	85.8	34.7	9.2	117.0	.3	7.5	4.1	4.6	1.1
35	145.8	4.1	135.8	108.3	48.5	11.6	128.6	.2	6.8	4.3	4.8	1.0
40	158.8	4.8	148.0	122.5	67.4	17.9	133.9	.2	8.8	5.9	7.3	2.7
45	168.7	6.4	160.0	137.9	87.6	28.1	143.3	.7	9.6	7.1	6.3	1.7
50	177.3	7.8	170.0	153.7	105.3	33.1	150.4	.1	10.9	5.5	7.4	3.1
55	161.3	10.0	153.5	134.1	81.5	24.8	130.1	.2	10.0	6.3	6.8	7.9
60	153.7	12.8	140.2	127.0	93.7	35.5	128.4	--	5.2	7.2	10.6	2.3
65	206.0	17.9	199.0	188.2	150.1	67.4	172.9	.7	12.8	4.3	10.3	5.0
70	158.7	22.0	150.1	138.0	104.5	34.7	132.7	1.0	11.6	6.0	3.8	3.6
75	189.5	7.5	179.2	173.7	126.7	44.0	167.5	--	5.3	1.1	.7	14.9
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 3a.--Average empirical yields of timber for fully stocked stands

Type: Natural loblolly pine **Site:** Medium (SI 60-78) **Region:** Coastal Plain

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
								Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
		1.0+	5.0+	9.0+	13.0+	17.0+					Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	10	1,463	63	--	--	--	12	773	155	139	--	--
15	20	1,444	184	13	--	--	46	1,479	137	645	73	385
20	40	1,646	237	28	4	--	67	2,014	83	1,053	275	1,465
25	25	1,128	295	50	11	2	94	2,636	128	1,698	721	3,822
30	43	1,091	274	76	13	2	103	2,795	82	1,944	957	5,067
35	30	1,279	292	80	16	1	109	3,160	153	2,202	1,122	5,934
40	29	885	255	96	18	2	110	3,148	139	2,320	1,364	7,225
45	22	871	212	97	29	4	110	3,361	102	2,564	1,868	9,880
50	14	1,052	209	119	43	9	127	4,227	181	3,315	2,669	14,126
55	6	1,120	170	108	33	7	108	3,643	264	2,859	2,314	12,252
60	5	1,129	209	100	43	11	123	3,966	451	3,028	2,495	13,201
65	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 3b.--Average empirical yields of forest biomass for fully stocked stands

Type: Natural loblolly pine **Site:** Medium (SI 60-78) **Region:** Coastal Plain

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	27.1	5.3	7.5	--	--	--	24.7	--	1.5	--	0.9	--
15	53.9	4.8	32.7	5.6	--	--	45.0	--	3.4	1.6	3.5	0.3
20	74.3	3.0	51.9	16.7	4.2	--	61.6	--	3.8	2.6	5.0	1.4
25	97.3	4.8	81.1	37.1	15.0	4.4	84.5	0.2	4.8	2.4	4.2	1.0
30	103.5	3.0	90.3	51.5	16.5	3.6	90.1	.4	5.2	3.2	3.2	1.3
35	117.4	5.7	101.8	59.5	20.0	2.6	97.6	.2	6.5	4.1	6.5	2.6
40	116.7	5.2	105.7	72.7	23.1	4.6	99.7	--	5.2	2.9	5.4	3.5
45	124.2	3.7	112.9	89.2	43.3	9.9	110.6	.2	4.4	3.0	5.0	1.0
50	155.8	6.5	143.0	124.5	69.5	20.7	133.1	--	8.9	7.2	3.7	2.9
55	135.0	9.9	122.1	109.4	53.0	15.2	119.9	.8	4.6	3.6	4.7	1.5
60	147.2	17.2	133.2	111.8	72.9	27.4	123.2	.9	1.9	6.3	11.2	3.7
65	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 4a.--Average empirical yields of timber for fully stocked stands

Type: Natural loblolly pine **Site:** Medium (SI 60-78) **Region:** Piedmont

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
								Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
		1.0+	5.0+	9.0+	13.0+	17.0+					Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	13	1,336	96	--	--	--	18	721	152	222	--	--
15	17	1,379	217	23	--	--	58	1,466	211	741	134	710
20	26	1,490	279	33	2	--	74	1,905	162	1,068	240	1,276
25	29	1,171	319	45	3	1	95	2,371	98	1,466	413	2,189
30	33	954	318	72	9	1	110	2,654	121	1,905	792	4,203
35	32	993	281	80	13	1	105	2,748	166	1,984	967	5,130
40	26	877	251	95	21	3	110	3,097	161	2,332	1,455	7,719
45	21	1,041	256	89	19	2	106	3,051	201	2,257	1,345	7,134
50	3	1,231	237	103	20	4	111	3,187	183	2,455	1,764	9,324
55	6	809	226	91	38	7	118	3,468	268	2,771	2,033	10,787
60	--	--	--	--	--	--	--	--	--	--	--	--
65	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 4b.--Average empirical yields of forest biomass for fully stocked stands

Type: Natural loblolly pine **Site:** Medium (SI 60-78) **Region:** Piedmont

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	25.9	5.3	12.2	--	--	--	22.1	--	0.8	1.8	0.9	0.3
15	53.3	7.6	37.4	8.8	--	--	50.8	0.1	2.0	0.4	--	--
20	69.5	6.0	51.3	15.3	2.3	--	62.3	.2	4.2	.9	1.5	.5
25	86.3	3.6	69.8	23.6	4.7	2.5	78.5	.3	4.0	1.3	1.8	.4
30	97.7	4.5	87.7	44.2	10.9	2.6	86.4	.4	4.4	2.8	1.9	1.8
35	101.1	6.1	90.2	52.9	14.7	2.0	89.2	--	4.3	3.2	1.8	2.5
40	114.2	6.0	103.6	74.8	28.8	6.5	98.2	1.0	6.2	2.5	4.9	1.5
45	111.9	7.3	100.7	69.9	25.8	4.4	96.9	1.0	6.1	2.7	3.1	2.1
50	117.7	6.4	106.1	85.8	31.7	9.0	97.0	--	10.4	6.3	2.7	1.4
55	126.7	10.1	119.9	93.1	55.9	15.3	114.5	.1	5.9	3.2	2.7	.4
60	--	--	--	--	--	--	--	--	--	--	--	--
65	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 5a.--Average empirical yields of timber for fully stocked stands

Type: Planted loblolly pine **Site:** Medium (SI 60-78) **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
								Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
		1.0+	5.0+	9.0+	13.0+	17.0+					Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	96	1,217	78	--	--	--	14	643	49	139	--	--
15	44	1,230	266	17	--	--	65	1,602	113	855	97	515
20	35	907	351	35	1	--	98	2,276	154	1,460	251	1,327
25	22	841	366	63	1	--	112	2,684	149	1,877	463	2,444
30	3	521	335	127	2	--	134	3,199	313	2,576	1,057	5,583
35	2	851	360	105	33	--	144	3,511	481	2,739	1,381	7,297
40	--	--	--	--	--	--	--	--	--	--	--	--
45	--	--	--	--	--	--	--	--	--	--	--	--
50	--	--	--	--	--	--	--	--	--	--	--	--
55	--	--	--	--	--	--	--	--	--	--	--	--
60	--	--	--	--	--	--	--	--	--	--	--	--
65	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 5b.--Average empirical yields of forest biomass for fully stocked stands

Type: Planted loblolly pine **Site:** Medium (SI 60-78) **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	22.9	1.8	8.0	--	--	--	20.6	--	0.8	0.5	0.6	0.3
15	58.6	4.2	43.1	6.9	--	--	54.4	0.2	1.0	1.0	1.5	.5
20	83.9	5.7	71.5	16.1	1.0	--	79.9	.1	1.2	.9	1.4	.5
25	99.5	5.6	89.4	29.9	1.1	0.4	93.1	.2	1.8	1.1	2.7	.6
30	117.6	10.3	115.1	64.4	2.3	--	117.2	--	.4	--	--	--
35	129.9	17.3	124.4	70.6	35.5	--	127.9	--	.8	.4	--	.8
40	--	--	--	--	--	--	--	--	--	--	--	--
45	--	--	--	--	--	--	--	--	--	--	--	--
50	--	--	--	--	--	--	--	--	--	--	--	--
55	--	--	--	--	--	--	--	--	--	--	--	--
60	--	--	--	--	--	--	--	--	--	--	--	--
65	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 6a.--Average empirical yields of timber for fully stocked stands

Type: Planted loblolly pine **Site:** High (SI 79+) **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
								Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
		1.0+	5.0+	9.0+	13.0+	17.0+					Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	39	928	168	3	--	--	36	989	143	440	15	80
15	28	888	340	51	1	--	101	2,360	158	1,565	377	1,989
20	28	834	355	76	2	--	119	2,933	160	2,122	632	3,341
25	26	560	333	116	9	1	133	3,388	168	2,660	1,314	6,943
30	11	481	284	120	15	--	125	3,382	230	2,731	1,513	7,993
35	1	834	235	146	39	2	143	4,818	--	3,974	3,158	16,717
40	2	338	188	130	44	3	126	3,607	231	2,858	2,301	12,185
45	--	--	--	--	--	--	--	--	--	--	--	--
50	--	--	--	--	--	--	--	--	--	--	--	--
55	--	--	--	--	--	--	--	--	--	--	--	--
60	--	--	--	--	--	--	--	--	--	--	--	--
65	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 6b.--Average empirical yields of forest biomass for fully stocked stands

Type: Planted loblolly pine **Site:** High (SI 79+) **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	35.6	5.2	22.9	1.0	--	--	34.0	--	0.7	0.4	0.3	0.2
15	87.1	5.9	75.9	24.0	0.5	--	83.5	0.2	.9	1.7	.5	.3
20	108.5	5.9	98.7	39.1	2.2	--	103.4	--	1.6	1.3	2.0	.2
25	125.3	6.2	121.3	73.5	10.6	1.2	123.6	--	1.2	.3	.2	.1
30	124.8	8.5	120.3	81.9	20.1	1.2	120.2	--	3.2	1.1	--	.3
35	177.0	--	171.4	151.9	58.7	5.1	156.0	--	6.8	5.1	--	9.1
40	132.8	9.5	131.0	118.8	59.1	9.2	111.1	--	5.6	4.2	10.3	1.5
45	--	--	--	--	--	--	--	--	--	--	--	--
50	--	--	--	--	--	--	--	--	--	--	--	--
55	--	--	--	--	--	--	--	--	--	--	--	--
60	--	--	--	--	--	--	--	--	--	--	--	--
65	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 7a.--Average empirical yields of timber for fully stocked stands

Type: Natural slash pine **Site:** Medium (SI 62-80) **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
								Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
		1.0+	5.0+	9.0+	13.0+	17.0+					Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	3	863	22	--	--	--	5	255	41	76	--	--
15	2	1,100	199	5	--	--	41	1,421	653	635	65	345
20	9	1,107	282	26	2	--	76	2,161	237	1,137	218	1,152
25	36	1,085	326	49	5	1	96	2,746	134	1,742	573	3,026
30	22	954	301	55	8	2	96	2,719	156	1,743	666	3,517
35	23	1,129	343	56	7	1	106	3,189	179	2,094	799	4,228
40	19	888	319	76	15	3	111	3,316	248	2,285	1,153	6,088
45	12	572	250	95	15	1	107	3,188	168	2,407	1,388	7,333
50	5	972	359	110	11	2	132	3,956	370	2,831	1,444	7,621
55	8	820	258	107	26	5	124	3,771	192	2,872	1,883	9,976
60	--	--	--	--	--	--	--	--	--	--	--	--
65	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 7b.--Average empirical yields of forest biomass for fully stocked stands

Type: Natural slash pine **Site:** Medium (62-80) **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	9.5	1.6	3.8	--	--	--	9.1	--	--	0.5	--	--
15	51.7	24.1	32.1	3.3	--	--	48.0	3.4	--	.3	--	--
20	80.8	8.9	55.7	12.2	0.9	--	79.5	--	0.8	.2	0.1	0.2
25	103.6	5.1	83.4	31.3	6.5	1.9	96.2	3.3	1.3	1.1	1.4	.4
30	101.1	5.9	83.5	36.8	10.2	3.8	91.2	1.4	3.0	4.0	.6	1.0
35	120.1	6.9	98.7	42.4	9.7	1.6	110.7	.7	2.0	5.9	.3	.5
40	124.8	9.3	107.4	60.2	20.3	5.6	108.7	8.4	4.0	1.5	2.2	--
45	122.2	6.6	111.2	73.3	20.2	1.5	117.6	--	.9	--	3.3	.3
50	147.4	13.0	130.6	79.2	15.4	3.1	119.5	16.3	9.7	1.9	--	--
55	141.4	7.7	127.7	93.9	39.0	10.9	119.4	7.0	10.0	3.2	.9	1.0
60	--	--	--	--	--	--	--	--	--	--	--	--
65	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 8a.--Average empirical yields of timber for fully stocked stands

Type: Natural slash pine **Site:** High (SI 81+) **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
								Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
		1.0+	5.0+	9.0+	13.0+	17.0+					Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	--	--	--	--	--	--	--	--	--	--	--	--
15	--	--	--	--	--	--	--	--	--	--	--	--
20	5	1,002	342	48	16	1	108	2,671	347	1,587	398	2,102
25	25	923	333	81	6	1	111	3,254	184	2,288	1,000	5,286
30	39	615	263	102	14	2	114	3,479	130	2,697	1,677	8,864
35	28	631	252	106	23	2	118	3,652	164	2,852	1,868	9,867
40	20	592	267	108	25	2	122	3,789	158	3,007	1,991	10,529
45	21	584	216	110	37	6	120	3,935	199	3,142	2,531	13,374
50	2	628	268	128	51	23	154	4,900	2,317	4,015	3,522	18,662
55	2	596	206	145	50	2	143	4,893	647	3,864	3,263	17,261
60	5	963	231	115	55	13	143	5,017	498	4,078	3,367	17,889
65	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 8b.--Average empirical yields of forest biomass for fully stocked stands

Type: Natural slash pine **Site:** High (SI 81+) **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	--	--	--	--	--	--	--	--	--	--	--	--
15	--	--	--	--	--	--	--	--	--	--	--	--
20	96.7	12.1	79.6	24.3	9.7	0.6	89.7	0.1	2.1	0.7	0.5	3.6
25	123.2	6.9	106.1	55.2	8.3	2.1	117.6	.5	2.3	1.0	1.4	0.3
30	132.7	5.0	122.2	86.0	22.7	4.6	128.7	.2	1.2	1.0	1.4	--
35	139.4	6.3	129.4	94.2	33.3	4.7	130.8	1.6	3.0	2.2	1.6	--
40	144.3	5.8	135.3	99.8	36.1	4.2	136.9	--	4.5	2.4	.3	.1
45	149.9	7.4	140.7	119.5	61.3	14.8	136.6	2.8	5.5	3.1	1.7	.2
50	187.3	88.5	180.3	158.7	113.5	68.4	157.9	--	10.5	5.0	10.9	2.9
55	186.9	25.5	174.8	160.3	78.9	5.7	169.0	--	6.0	7.9	3.9	--
60	188.4	18.4	179.4	153.8	106.2	39.4	151.9	4.5	21.6	3.1	7.3	--
65	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 9a.--Average empirical yields of timber for fully stocked stands

Type: Planted slash pine **Site:** Medium (SI 62-80) **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
		1.0+	5.0+	9.0+	13.0+	17.0+		Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
											Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	74	699	55	--	--	--	9	587	49	101	--	--
15	123	774	236	2	--	--	47	1,341	45	604	11	57
20	138	734	320	11	1	--	76	1,894	58	1,144	96	508
25	48	664	327	26	1	--	88	2,247	87	1,500	231	1,223
30	11	592	270	63	1	--	90	2,409	276	1,733	602	3,180
35	4	574	314	51	7	1	97	2,287	429	1,537	527	2,800
40	3	727	227	74	25	3	98	2,709	344	2,119	1,458	7,719
45	--	--	--	--	--	--	--	--	--	--	--	--
50	--	--	--	--	--	--	--	--	--	--	--	--
55	--	--	--	--	--	--	--	--	--	--	--	--
60	--	--	--	--	--	--	--	--	--	--	--	--
65	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 9b.--Average empirical yields of forest biomass for fully stocked stands

Type: Planted slash pine **Site:** Medium (SI 62-80) **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	21.4	1.8	5.5	--	--	--	20.8	--	--	--	0.5	--
15	49.7	1.7	31.8	0.7	--	--	48.6	--	0.1	0.2	.6	0.2
20	71.5	2.3	57.4	5.6	0.6	--	69.4	0.1	.1	.3	1.5	.2
25	85.5	3.4	73.1	13.7	1.3	--	83.9	--	.3	.1	1.0	.1
30	91.4	10.1	81.9	35.4	1.3	0.2	87.1	2.2	.3	.6	.6	.6
35	87.0	16.6	76.4	30.3	8.8	2.0	83.7	--	--	--	3.3	--
40	104.7	13.4	96.8	69.7	33.5	4.8	94.2	--	2.1	--	8.5	--
45	--	--	--	--	--	--	--	--	--	--	--	--
50	--	--	--	--	--	--	--	--	--	--	--	--
55	--	--	--	--	--	--	--	--	--	--	--	--
60	--	--	--	--	--	--	--	--	--	--	--	--
65	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 10a.--Average empirical yields of timber for fully stocked stands

Type: Planted slash pine **Site:** High (SI 81+) **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
		1.0+	5.0+	9.0+	13.0+	17.0+		Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
											Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	13	693	173	1	--	--	37	1,002	189	415	5	27
15	29	771	330	11	1	--	76	1,875	146	1,113	89	472
20	76	743	375	39	2	--	104	2,636	89	1,832	347	1,832
25	61	496	331	70	2	--	111	2,874	103	2,246	713	3,767
30	7	496	248	115	16	--	109	3,057	389	2,448	1,538	8,125
35	3	626	185	123	22	1	110	3,513	402	2,938	2,369	12,514
40	4	364	169	140	49	2	131	4,500	650	3,933	3,427	18,105
45	--	--	--	--	--	--	--	--	--	--	--	--
50	--	--	--	--	--	--	--	--	--	--	--	--
55	--	--	--	--	--	--	--	--	--	--	--	--
60	--	--	--	--	--	--	--	--	--	--	--	--
65	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 10b.--Average empirical yields of forest biomass for fully stocked stands

Type: Planted slash pine **Site:** High (SI 81+) **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	36.9	7.2	21.3	0.4	--	--	36.8	--	--	--	0.1	--
15	70.2	5.6	56.0	5.4	0.7	--	68.6	--	0.8	0.3	.4	0.1
20	100.4	3.4	89.3	21.3	2.1	0.2	97.1	--	1.3	.6	1.2	.2
25	110.1	4.0	105.8	42.2	2.7	.3	108.2	--	.9	.3	.5	.2
30	116.2	14.8	109.8	81.5	20.2	--	113.8	--	2.4	.1	--	--
35	134.4	16.4	129.1	117.6	30.0	3.1	133.1	--	.3	--	.6	.4
40	173.8	25.3	172.4	161.5	75.6	4.6	172.4	--	--	.3	1.1	--
45	--	--	--	--	--	--	--	--	--	--	--	--
50	--	--	--	--	--	--	--	--	--	--	--	--
55	--	--	--	--	--	--	--	--	--	--	--	--
60	--	--	--	--	--	--	--	--	--	--	--	--
65	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 11a.--Average empirical yields of timber for fully stocked stands

Type: Natural shortleaf pine **Site:** Medium (SI 54-71) **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
								Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
		1.0+	5.0+	9.0+	13.0+	17.0+					Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	4	1,283	14	--	--	--	2	319	89	18	--	--
15	9	1,458	181	13	--	--	45	1,212	216	590	58	309
20	11	1,363	308	26	3	--	79	2,025	190	1,138	180	954
25	18	1,149	313	35	3	--	88	2,168	134	1,351	286	1,515
30	18	1,282	293	44	5	--	91	2,490	192	1,540	431	2,294
35	21	1,099	318	67	6	--	104	2,665	124	1,822	657	3,482
40	16	880	266	83	12	1	108	2,868	131	2,144	973	5,186
45	6	1,275	295	78	4	--	97	2,720	238	1,798	689	3,663
50	3	1,235	203	79	13	--	86	2,874	421	1,923	1,144	6,052
55	8	716	295	106	18	3	126	3,703	224	2,870	1,620	8,658
60	4	795	310	101	15	2	127	3,461	296	2,567	1,264	6,712
65	4	799	249	88	12	1	99	2,625	180	1,948	1,052	5,555
70	3	1,184	217	75	19	1	96	2,990	109	2,188	1,289	6,811
75	1	632	232	165	43	--	139	3,822	--	3,140	2,296	12,169
80	2	680	229	142	65	12	158	4,957	473	4,019	3,355	17,867

Table 11b.--Average empirical yields of forest biomass for fully stocked stands

Type: Natural shortleaf pine **Site:** Medium (SI 54-71) **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	12.3	3.5	1.2	--	--	--	11.0	0.4	--	--	0.2	0.7
15	43.0	7.6	26.7	5.1	--	--	39.1	.5	3.1	--	.1	.3
20	71.2	6.8	51.3	11.7	3.0	--	61.9	1.8	2.6	2.4	1.4	1.1
25	76.6	4.7	61.1	17.0	2.7	0.3	66.6	1.2	2.8	2.6	1.2	2.1
30	89.4	7.0	69.3	25.8	4.9	.4	72.1	1.4	5.7	2.1	4.9	3.3
35	95.1	4.6	80.6	37.7	6.3	.6	81.2	1.3	4.7	2.6	1.7	3.6
40	103.3	4.8	92.6	53.7	15.2	3.3	88.0	1.2	1.7	3.7	5.1	3.6
45	98.1	8.6	79.7	44.1	4.3	.5	73.3	.1	5.4	8.1	2.8	8.4
50	104.1	16.2	80.8	57.8	16.7	--	86.5	1.7	3.7	1.4	7.0	3.8
55	135.0	8.5	126.2	89.0	28.0	8.1	106.0	--	4.0	6.2	13.8	5.0
60	127.7	9.7	117.1	71.2	17.6	3.8	110.8	--	5.1	1.8	7.6	2.4
65	93.8	6.3	85.4	56.3	13.0	1.1	84.5	.6	2.0	1.5	1.8	3.3
70	108.3	5.0	92.3	61.5	23.1	2.8	97.9	1.5	3.9	0.4	2.7	1.9
75	138.0	--	133.5	124.0	46.0	--	110.1	3.2	20.4	--	4.2	--
80	178.2	15.9	173.3	155.6	97.9	27.0	147.8	.9	14.2	11.9	--	3.4

Table 12a.--Average empirical yields of timber for fully stocked stands

Type: Natural longleaf pine **Site:** All sites **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
								Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
		1.0+	5.0+	9.0+	13.0+	17.0+					Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	2	152	33	12	--	--	15	410	--	345	155	818
15	2	871	22	22	2	--	13	533	53	226	168	888
20	2	921	121	3	--	--	32	811	610	416	27	140
25	10	866	236	50	4	--	75	2,105	287	1,375	582	3,073
30	17	720	182	53	7	--	67	1,829	182	1,269	641	3,390
35	14	690	236	55	11	1	86	2,494	235	1,785	911	4,811
40	21	539	218	79	15	1	91	2,541	172	1,979	1,211	6,398
45	31	555	198	75	15	1	86	2,449	136	1,894	1,250	6,605
50	23	437	201	97	22	1	99	3,121	191	2,512	1,834	9,692
55	19	460	165	104	27	3	99	3,247	225	2,653	2,147	11,343
60	11	350	161	96	22	2	88	2,588	173	2,155	1,723	9,101
65	4	773	217	126	30	4	121	4,115	994	3,415	2,666	14,095
70	11	366	177	114	32	2	108	3,368	297	2,839	2,406	12,729
75	8	317	112	76	34	2	78	2,615	442	2,201	1,983	10,473
80	3	504	138	78	25	7	83	2,591	527	2,191	1,989	10,506

Table 12b.--Average empirical yields of forest biomass for fully stocked stands

Type: Natural longleaf pine **Site:** All sites **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	16.0	--	15.7	8.2	--	--	16.0	--	--	--	--	--
15	19.5	2.1	9.8	9.8	1.2	--	19.5	--	--	--	--	--
20	29.4	22.1	19.6	1.4	--	--	29.1	--	--	--	0.3	--
25	80.0	11.1	66.0	31.5	3.9	--	68.8	--	3.0	3.9	3.6	0.7
30	69.4	7.0	59.5	34.3	8.6	0.9	65.4	--	0.5	0.7	2.1	.7
35	95.4	9.2	84.1	45.5	16.3	1.9	91.9	--	.4	.3	2.6	.1
40	98.2	6.8	91.3	61.5	19.0	1.9	93.9	--	.7	.2	1.8	1.6
45	94.6	5.4	87.6	63.0	20.2	1.8	89.6	--	.9	.7	3.2	.1
50	121.1	7.5	114.4	90.0	31.1	3.4	117.9	0.3	.3	.3	2.1	.2
55	126.5	8.9	119.2	103.3	41.9	7.8	123.2	--	1.8	--	1.4	--
60	101.9	6.9	97.9	84.1	30.8	5.2	97.5	--	--	.1	3.6	.8
65	159.8	38.0	152.6	130.8	49.6	8.9	151.6.	.3	1.3	4.3	2.2	--
70	132.3	11.7	128.5	115.0	49.6	7.2	127.0	--	.4	--	4.9	--
75	102.3	17.4	98.7	90.2	54.1	6.0	99.7	--	.3	--	2.1	.2
80	101.2	21.1	98.0	89.8	49.4	20.1	100.4	--	.2	--	.3	.3

Table 13a.--Average empirical yields of timber for fully stocked stands

Type: Natural Virginia pine **Site:** Medium (SI 57-66) **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
		1.0+	5.0+	9.0+	13.0+	17.0+		Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
											Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	14	1,154	61	--	--	--	12	751	107	135	--	--
15	14	1,985	149	6	--	--	33	1,770	168	457	18	95
20	27	1,821	210	11	1	--	50	2,127	133	730	68	367
25	30	1,203	297	34	3	--	83	2,562	127	1,398	283	1,505
30	21	1,024	344	53	5	--	106	3,002	118	1,927	490	2,593
35	22	1,068	310	56	5	--	95	2,850	160	1,789	505	2,678
40	14	923	309	68	6	--	106	2,914	197	2,064	676	3,592
45	8	744	357	119	7	--	135	3,882	179	2,917	1,274	6,762
50	4	1,243	269	137	13	1	118	3,596	121	2,511	1,481	7,851
55	3	1,115	281	75	11	2	101	2,994	229	2,069	798	4,285
60	2	879	259	52	3	--	79	2,602	242	1,526	508	2,738
65	3	871	304	109	19	1	129	3,739	606	2,793	1,286	6,965
70	1	709	308	100	29	--	143	3,953	--	3,002	1,812	9,609
75	--	--	--	--	--	--	--	--	--	--	--	--
80	1	717	217	107	33	2	116	3,343	--	2,717	1,623	8,574

Table 13b.--Average empirical yields of forest biomass for fully stocked stands

Type: Natural Virginia pine **Site:** Medium (SI 57-66) **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	28.4	4.0	8.9	--	--	--	25.9	0.5	0.2	0.7	0.6	0.5
15	66.4	6.2	25.7	3.0	--	--	59.7	.3	1.5	2.4	1.2	1.4
20	80.2	4.9	39.9	5.7	0.8	--	70.0	1.2	1.0	3.5	1.5	3.1
25	97.3	4.7	70.6	18.8	3.5	0.8	84.9	1.4	2.6	2.4	2.4	3.6
30	113.3	4.5	92.9	30.1	4.8	.5	99.4	1.8	.9	3.2	3.6	4.4
35	107.6	5.9	85.2	32.1	5.3	.7	93.3	.2	2.8	2.7	5.9	2.7
40	109.2	7.4	96.5	43.3	5.5	.3	92.5	1.4	5.0	5.7	2.5	2.2
45	144.5	6.0	133.7	79.5	9.7	.6	127.0	.1	3.5	4.4	6.0	3.5
50	132.8	4.1	113.3	88.9	16.8	2.1	112.2	.8	2.5	6.6	2.9	7.6
55	115.2	10.7	99.2	54.7	16.2	5.1	83.5	1.1	2.0	2.2	21.9	4.4
60	96.7	10.7	70.5	31.6	4.4	.0	84.7	--	.3	1.9	2.3	7.5
65	144.4	23.9	132.7	85.5	24.6	1.3	93.5	--	4.0	5.8	38.1	3.0
70	146.9	--	136.7	92.3	36.1	--	130.8	2.3	--	4.4	--	9.3
75	--	--	--	--	--	--	--	--	--	--	--	--
80	122.0	--	115.2	86.0	37.8	3.6	115.2	.5	--	--	--	6.3

Table 14a.--Average empirical yields of timber for fully stocked stands

Type: Natural Virginia pine **Site:** High (SI 67+) **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
								Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
		1.0+	5.0+	9.0+	13.0+	17.0+					Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	3	1,438	138	--	--	--	38	1,369	730	388	--	--
15	2	1,128	228	12	--	--	59	2,410	656	1,066	61	323
20	7	1,169	212	14	2	1	56	2,098	191	923	135	743
25	11	780	313	54	2	--	98	2,614	154	1,721	426	2,265
30	14	902	329	70	4	--	107	3,040	124	2,040	615	3,252
35	11	969	307	90	7	2	118	3,615	179	2,635	1,003	5,354
40	13	1,000	320	97	13	--	124	3,746	253	2,766	1,220	6,457
45	3	547	246	132	20	--	124	3,614	519	2,871	1,707	9,016
50	6	729	316	103	18	3	129	4,107	294	3,242	1,562	8,329
55	--	--	--	--	--	--	--	--	--	--	--	--
60	--	--	--	--	--	--	--	--	--	--	--	--
65	1	767	267	125	5	2	128	3,956	--	2,743	1,364	7,266
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 14b.--Average empirical yields of forest biomass for fully stocked stands

Type: Natural Virginia pine **Site:** High (SI 67+) **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	51.8	28.5	26.9	--	--	--	48.6	--	--	--	0.2	2.9
15	90.2	27.0	51.9	4.5	--	--	89.9	--	0.1	--	--	0.2
20	79.7	7.6	47.9	9.6	3.8	1.4	69.8	1.7	--	1.2	3.1	3.9
25	98.4	5.6	84.6	28.7	3.0	--	91.4	1.5	.4	2.5	2.2	.3
30	114.4	4.5	96.6	38.8	4.1	0.5	109.1	--	1.2	3.1	.7	.3
35	135.7	7.0	119.8	62.5	9.9	5.0	119.4	1.3	1.2	5.1	6.7	2.0
40	140.1	9.2	125.3	70.6	16.1	.7	126.8	1.3	1.5	3.1	2.9	4.6
45	132.2	18.5	124.7	94.6	22.2	--	126.9	--	--	2.0	.7	2.6
50	154.3	11.4	147.0	88.9	27.3	8.0	133.3	0.8	--	5.8	8.3	6.0
55	--	--	--	--	--	--	--	--	--	--	--	--
60	--	--	--	--	--	--	--	--	--	--	--	--
65	146.9	--	135.4	95.0	9.5	4.9	115.8	--	--	20.1	--	11.0
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 15a.--Average empirical yields of timber for fully stocked stands

Type: Natural pond pine **Site:** All sites **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
								Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
		1.0+	5.0+	9.0+	13.0+	17.0+					Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	4	558	8	--	--	--	2	81	53	19	--	--
15	13	824	52	6	--	--	12	440	101	133	36	190
20	13	1,169	117	12	1	--	31	802	137	388	98	522
25	22	1,194	201	29	2	--	59	1,494	135	862	254	1,343
30	30	1,053	200	34	5	1	63	1,563	169	968	361	1,907
35	20	1,108	267	58	8	--	91	2,293	197	1,615	662	3,500
40	25	911	232	57	10	2	85	2,039	177	1,496	737	3,894
45	26	1,054	222	70	17	3	91	2,394	181	1,777	1,047	5,537
50	17	925	270	65	14	1	96	2,529	274	1,859	967	5,112
55	6	1,058	195	83	18	3	90	2,578	251	1,921	1,374	7,298
60	14	1,406	223	97	22	4	105	3,144	93	2,258	1,534	8,120
65	3	1,938	136	64	16	1	73	2,397	22	1,504	1,108	5,852
70	3	1,016	150	74	24	5	86	2,384	311	1,777	1,387	7,340
75	4	1,702	153	80	17	2	85	2,558	364	1,767	1,316	6,950
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 15b.--Average empirical yields of forest biomass for fully stocked stands

Type: Natural pond pine **Site:** All sites **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	3.0	1.9	0.9	--	--	--	3.0	--	--	--	--	--
15	17.5	4.0	7.2	2.4	--	--	16.0	0.1	0.3	1.0	--	0.1
20	30.9	4.9	19.3	5.8	0.7	--	26.9	--	.4	1.1	1.6	.9
25	56.9	4.7	41.2	14.7	2.1	0.3	50.9	.9	1.6	2.9	0.2	.4
30	60.4	5.9	46.6	20.1	6.4	2.5	53.1	1.0	2.9	1.9	1.2	.2
35	84.5	6.4	73.7	37.4	9.4	.4	72.8	1.9	3.5	4.1	.3	1.8
40	77.5	5.7	67.5	38.8	13.9	4.2	68.2	.9	4.7	3.1	.3	.2
45	88.6	6.1	78.3	52.9	22.5	5.3	77.7	--	2.8	6.0	1.4	.8
50	94.3	9.1	82.9	50.3	20.3	2.6	79.0	--	2.4	11.4	.8	.7
55	93.1	9.3	82.8	65.7	27.1	7.6	79.7	.1	7.9	4.8	--	.5
60	113.7	3.5	97.2	75.2	33.8	9.8	91.9	--	4.6	14.8	.3	2.1
65	87.7	1.3	64.9	52.1	21.2	2.8	68.8	--	11.9	3.3	.6	3.1
70	89.2	9.5	79.1	64.8	33.5	10.4	74.5	2.5	8.3	1.3	1.0	1.5
75	94.8	11.8	77.6	64.1	21.4	3.2	75.9	1.9	10.2	4.4	--	2.3
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 16a.--Average empirical yields of timber for fully stocked stands

Type: Natural oak-pine **Site:** Medium **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
		1.0+	5.0+	9.0+	13.0+	17.0+		Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
											Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	21	967	42	--	--	--	10	464	75	122	--	--
15	16	1,502	110	14	--	--	30	1,100	139	443	71	386
20	30	1,512	205	30	4	--	61	1,963	111	989	261	1,430
25	31	1,320	222	41	9	1	74	2,145	145	1,214	437	2,358
30	36	1,255	253	53	10	2	86	2,425	106	1,470	541	2,946
35	40	1,122	243	67	17	4	96	2,809	138	1,802	856	4,662
40	44	1,102	240	63	12	2	90	2,615	83	1,695	717	3,904
45	38	1,011	245	78	18	5	104	3,028	90	2,036	949	5,211
50	44	984	249	92	25	5	115	3,430	126	2,356	1,294	7,019
55	23	925	229	85	24	6	107	3,199	179	2,218	1,204	6,574
60	23	1,043	239	91	31	5	115	3,541	211	2,324	1,411	7,656
65	14	1,061	213	81	30	7	108	3,185	186	2,105	1,339	7,254
70	18	743	247	86	31	10	120	3,489	188	2,516	1,627	8,935
75	8	831	183	87	32	8	105	3,265	203	2,366	1,669	9,103
80	9	940	205	91	33	8	112	3,417	161	2,429	1,513	8,341

Table 16b.--Average empirical yields of forest biomass for fully stocked stands

Type: Natural oak-pine **Site:** Medium **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	17.6	2.8	6.1	--	--	--	6.3	0.6	5.4	1.6	2.1	1.6
15	42.0	5.3	22.5	7.0	--	--	15.8	1.0	10.1	5.3	7.0	2.8
20	73.7	4.1	49.7	19.2	5.3	--	29.8	3.7	9.0	12.9	13.9	4.3
25	80.1	5.2	61.0	28.9	11.0	2.7	32.8	3.0	14.8	8.7	14.9	5.9
30	90.8	3.8	73.0	38.4	14.4	4.4	36.5	2.4	15.0	11.1	19.3	6.4
35	104.7	4.8	88.6	55.5	25.9	9.3	38.0	9.0	18.1	10.2	23.2	6.2
40	99.3	3.0	82.7	48.4	16.8	4.0	38.6	3.1	12.5	9.0	28.7	7.5
45	113.8	3.2	99.0	65.5	29.3	11.8	41.1	5.3	12.2	15.3	31.6	8.4
50	127.9	4.5	112.3	81.9	38.5	13.7	46.9	8.7	23.5	15.0	24.6	9.2
55	120.7	6.4	107.9	79.0	39.3	15.7	41.2	11.3	11.0	16.2	34.9	6.1
60	131.3	7.2	113.5	86.1	46.1	12.5	45.7	10.2	23.2	13.7	29.7	8.7
65	119.9	6.9	102.7	77.9	45.8	16.8	42.3	13.1	12.4	16.0	29.4	6.7
70	131.8	6.5	122.6	95.1	59.0	30.0	49.5	3.0	13.4	17.9	36.9	11.0
75	123.4	6.4	114.3	96.4	59.2	21.5	50.3	--	14.7	13.7	32.8	11.9
80	127.3	7.7	114.2	92.8	56.1	22.1	46.0	4.0	16.5	25.8	29.9	5.1

Table 17a.--Average empirical yields of timber for fully stocked stands

Type: Natural oak-pine **Site:** High **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
								Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
		1.0+	5.0+	9.0+	13.0+	17.0+					Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	4	1,099	75	28	--	--	29	964	170	574	204	1,115
15	5	1,112	87	18	5	--	29	936	79	507	233	1,234
20	7	1,214	248	55	16	3	93	2,577	303	1,560	629	3,429
25	2	1,449	197	22	10	2	62	1,742	238	1,112	433	2,297
30	30	991	258	78	25	7	111	3,278	130	2,299	1,286	6,956
35	25	866	251	80	23	6	111	3,205	145	2,200	1,216	6,615
40	31	871	228	86	33	10	117	3,596	151	2,567	1,641	8,925
45	28	759	229	87	37	12	120	3,636	128	2,672	1,814	9,967
50	17	792	234	100	38	12	129	4,056	183	3,006	2,001	10,994
55	20	712	217	87	38	11	118	3,788	173	2,818	1,875	10,296
60	15	898	217	88	41	13	122	3,920	196	2,807	2,094	11,461
65	6	771	175	99	51	21	138	4,751	297	3,514	2,933	16,298
70	11	682	176	92	53	25	139	4,850	238	3,726	3,229	17,686
75	2	579	180	94	62	19	134	4,092	624	3,007	2,743	14,752
80	4	1,035	244	99	46	17	142	4,976	843	3,650	2,831	15,479

Table 17b.--Average empirical yields of forest biomass for fully stocked stands

Type: Natural oak-pine **Site:** High **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	35.8	6.5	26.1	18.7	--	--	15.0	--	5.2	8.6	6.9	0.2
15	35.3	2.5	24.8	15.4	6.5	--	11.1	4.3	5.3	5.5	6.1	3.1
20	94.2	11.6	80.4	45.5	23.5	9.2	34.7	4.8	18.5	20.9	14.1	1.1
25	66.2	9.0	52.8	20.6	13.7	4.2	37.6	--	10.2	7.4	8.3	2.8
30	122.4	4.6	107.6	72.8	39.7	16.1	51.9	0.7	28.7	14.8	22.0	4.3
35	119.7	5.3	106.7	74.9	37.3	15.6	46.7	.7	25.1	15.2	23.1	8.9
40	134.4	5.7	121.9	94.6	59.7	27.8	51.2	4.1	20.1	19.9	32.7	6.3
45	136.4	4.8	126.6	101.5	68.8	33.3	50.1	4.0	29.2	13.4	32.4	7.3
50	150.1	6.9	139.1	113.9	74.6	37.0	52.8	1.4	37.5	22.1	27.8	8.5
55	143.1	6.6	132.0	106.6	70.9	30.3	47.0	2.7	23.5	20.5	37.2	12.3
60	147.2	7.8	136.6	114.9	84.2	43.3	58.3	.3	31.0	18.6	27.4	11.6
65	182.6	9.7	172.7	158.4	126.5	76.5	54.6	4.8	39.1	14.9	63.1	6.1
70	182.4	8.8	172.4	155.5	128.9	86.8	65.9	9.0	45.7	26.8	29.5	5.5
75	162.4	25.8	156.3	141.6	121.2	56.3	70.5	26.0	4.6	--	53.7	7.6
80	185.0	31.3	170.6	144.6	108.1	62.0	62.1	17.0	37.3	31.1	26.3	11.1

Table 18a.--Average empirical yields of timber for fully stocked stands

Type: Natural oak-pine **Site:** Medium **Region:** Coastal Plain

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
		1.0+	5.0+	9.0+	13.0+	17.0+		Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
											Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	10	946	45	--	--	--	9	482	134	121	--	--
15	5	1,879	118	11	--	--	31	1,252	213	445	69	364
20	21	1,420	202	33	5	--	63	1,925	126	1,025	312	1,707
25	20	1,364	227	48	10	1	78	2,342	182	1,354	559	3,001
30	14	1,092	322	62	12	3	106	2,805	158	1,794	703	3,792
35	25	1,161	250	74	20	5	103	3,039	195	1,968	1,054	5,719
40	15	1,204	236	61	16	2	90	2,768	178	1,694	853	4,567
45	15	995	218	75	20	5	101	3,017	164	1,997	1,046	5,679
50	28	1,035	254	96	25	5	117	3,470	183	2,389	1,345	7,247
55	13	804	234	95	33	9	118	3,520	193	2,517	1,544	8,399
60	15	1,119	246	101	35	6	122	3,850	278	2,441	1,581	8,547
65	7	1,254	195	77	33	5	100	3,083	334	1,935	1,342	7,186
70	9	907	242	92	35	14	128	3,902	259	2,763	2,059	11,221
75	5	877	177	90	35	9	109	3,445	300	2,458	1,786	9,791
80	5	1,005	205	80	33	7	107	3,257	258	2,259	1,388	7,641

Table 18b.--Average empirical yields of forest biomass for fully stocked stands

Type: Natural oak-pine **Site:** Medium Region: Coastal Plain

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	18.0	5.0	6.1	--	--	--	7.5	0.8	6.5	1.0	1.5	0.8
15	48.0	8.6	22.9	5.3	--	--	21.4	--	13.6	4.0	7.8	1.2
20	72.0	4.7	50.9	21.8	6.3	--	29.1	4.9	10.6	11.1	13.4	2.9
25	86.8	6.3	66.4	34.0	12.3	2.8	37.7	2.7	19.9	7.6	13.8	5.2
30	102.9	6.0	87.6	44.8	16.6	5.7	41.4	2.1	21.5	15.1	19.4	3.3
35	111.1	6.8	95.0	63.7	30.8	11.8	43.5	12.4	22.3	10.5	16.4	5.9
40	102.5	6.3	82.0	49.3	21.1	3.6	42.4	7.7	17.0	10.9	18.2	6.4
45	112.2	5.1	95.9	65.8	32.5	14.9	43.7	10.4	13.8	14.2	25.8	4.2
50	126.8	6.5	111.0	81.8	38.0	12.9	49.5	10.7	33.6	13.2	17.0	2.8
55	131.0	6.9	120.1	93.9	53.5	21.9	49.1	12.4	17.3	17.0	30.0	5.1
60	140.4	9.7	120.0	94.1	51.7	14.4	49.0	11.9	32.6	17.6	22.7	6.6
65	114.0	12.1	93.1	71.9	45.6	11.8	45.3	19.3	18.0	14.1	15.4	1.9
70	146.0	9.2	133.6	109.5	73.7	42.9	60.7	5.5	22.2	17.4	24.7	15.6
75	129.1	9.0	120.2	103.4	66.2	26.7	50.2	--	18.8	18.3	29.8	12.0
80	121.7	13.4	109.1	85.9	55.5	16.6	44.7	1.6	22.0	17.5	33.3	2.7

Table 19a.--Average empirical yields of timber for fully stocked stands

Type: Natural oak-pine **Site:** Medium **Region:** Piedmont

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
		1.0+	5.0+	9.0+	13.0+	17.0+		Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
											Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	9	936	47	--	--	--	11	465	102	138	--	--
15	11	1,330	106	15	--	--	30	1,031	180	441	72	395
20	7	1,820	206	27	2	--	58	2,105	294	912	162	878
25	11	1,241	214	29	7	1	66	1,786	210	958	216	1,191
30	19	1,365	197	49	9	1	72	2,144	121	1,250	460	2,522
35	15	1,057	231	55	13	2	85	2,424	129	1,527	528	2,899
40	25	1,060	243	63	11	2	91	2,566	92	1,712	682	3,743
45	20	983	265	79	17	4	107	3,053	118	2,099	899	4,974
50	14	923	231	88	25	6	110	3,397	126	2,315	1,247	6,878
55	5	1,224	184	68	13	2	81	2,481	220	1,495	683	3,830
60	6	966	219	66	20	4	94	2,714	140	1,886	967	5,312
65	3	825	225	86	36	12	123	3,504	95	2,476	1,664	9,149
70	6	613	267	81	30	8	116	3,252	246	2,430	1,285	7,185
75	1	367	187	52	34	3	90	2,926	--	2,355	1,804	9,668
80	3	946	212	109	34	6	118	3,637	202	2,639	1,687	9,276

Table 19b.--Average empirical yields of forest biomass for fully stocked stands

Type: Natural oak-pine **Site:** Medium **Region:** Piedmont

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	17.8	3.8	6.8	--	--	--	6.0	0.4	4.2	2.4	2.3	2.5
15	39.3	6.8	22.4	7.8	--	--	13.2	1.4	8.6	5.9	6.7	3.5
20	79.8	10.5	48.2	14.5	2.7	--	33.2	1.3	6.7	17.1	12.6	9.0
25	67.8	8.1	51.3	19.7	8.6	2.6	24.0	3.5	5.7	10.6	16.9	7.1
30	81.1	4.4	62.3	35.5	12.8	3.2	30.9	2.5	12.3	9.0	19.0	7.4
35	93.9	5.0	77.9	41.9	17.8	5.1	28.8	3.2	11.2	9.6	34.4	6.7
40	98.6	3.5	83.8	48.3	16.3	4.4	38.2	.9	11.7	6.2	33.6	8.0
45	115.4	4.5	101.6	64.9	28.0	10.5	40.9	.7	12.7	16.1	35.1	9.9
50	131.5	4.7	115.6	85.8	41.8	17.2	44.4	3.2	6.5	19.0	38.8	19.5
55	96.2	8.3	78.4	55.9	20.3	5.5	31.6	3.0	4.2	9.6	39.3	8.5
60	104.4	4.9	90.7	61.9	29.4	8.5	35.7	5.4	7.1	4.6	36.9	14.7
65	132.7	3.9	120.9	94.4	60.3	30.8	45.2	--	14.8	32.8	19.0	20.9
70	123.7	7.3	117.5	85.7	52.8	21.4	37.2	--	6.9	26.8	43.4	9.5
75	108.5	--	102.4	77.8	60.1	10.8	61.3	--	23.7	--	23.3	0.3
80	133.0	7.6	118.4	99.4	52.9	18.1	54.7	1.1	12.9	44.3	15.3	4.8

Table 20a.--Average empirical yields of timber for fully stocked stands

Type: Oak-hickory **Site:** Medium **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
		1.0+	5.0+	9.0+	13.0+	17.0+		Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
											Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	27	917	33	--	--	--	7	347	59	94	--	--
15	39	1,173	92	12	--	--	25	911	99	336	43	241
20	14	1,577	117	23	5	--	37	1,446	137	551	150	859
25	31	1,365	199	40	7	1	67	2,101	83	1,125	309	1,736
30	55	1,280	221	44	8	2	76	2,279	78	1,310	380	2,169
35	44	1,154	213	55	13	3	82	2,474	110	1,472	515	2,942
40	80	860	234	76	19	4	99	2,864	77	1,878	712	4,103
45	73	871	240	76	21	4	102	2,997	88	1,987	771	4,428
50	67	854	228	78	21	5	102	3,023	87	2,035	814	4,708
55	60	706	213	85	30	8	110	3,200	70	2,195	1,101	6,356
60	59	664	212	92	33	9	114	3,402	86	2,394	1,241	7,168
65	37	642	205	88	33	8	111	3,296	88	2,367	1,237	7,198
70	55	608	182	94	40	14	117	3,640	124	2,612	1,584	9,197
75	26	733	193	82	38	13	113	3,581	147	2,526	1,481	8,595
80	27	608	189	87	43	16	125	3,784	138	2,748	1,789	10,284

Table 20b.--Average empirical yields of forest biomass for fully stocked stands

Type: Oak-hickory **Site:** Medium **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	14.1	2.4	5.3	--	--	--	2.3	0.1	1.4	2.2	5.8	2.3
15	35.6	3.7	20.2	6.8	--	--	3.3	.7	6.1	8.5	11.8	5.2
20	57.3	5.0	30.6	15.8	5.6	--	4.9	--	5.4	13.2	26.4	7.3
25	81.9	3.2	60.4	29.4	10.1	3.7	9.3	1.4	14.2	13.1	32.2	11.5
30	89.5	3.0	69.9	36.1	14.5	7.1	9.9	.4	10.8	11.1	45.3	12.0
35	96.5	4.1	78.3	47.4	20.2	7.5	6.4	.8	13.1	20.2	39.6	16.4
40	112.6	2.8	99.9	68.2	31.8	12.6	6.1	.7	12.7	20.2	54.8	18.1
45	118.0	3.5	105.0	71.1	34.5	11.3	7.7	1.5	10.4	19.4	61.6	17.4
50	120.2	3.5	107.0	74.9	36.9	14.8	6.2	1.5	9.1	16.6	69.0	17.9
55	126.8	2.8	117.2	91.5	54.5	23.6	9.0	1.3	10.1	20.6	69.4	16.4
60	135.1	3.2	125.6	101.7	61.2	26.6	5.8	3.2	9.1	20.0	75.2	21.9
65	132.2	3.5	125.0	102.1	63.7	27.9	4.6	1.0	10.4	17.6	71.1	27.5
70	145.6	5.0	137.2	119.9	83.2	42.7	4.9	2.5	10.2	20.3	81.9	25.7
75	144.8	6.2	134.7	112.3	80.6	41.6	5.4	1.2	9.4	19.2	83.8	25.7
80	150.0	5.8	142.2	122.9	92.5	53.1	3.5	9.8	9.8	22.2	78.6	26.2

Table 21a.--Average empirical yields of timber for fully stocked stands

Type: Oak-hickory **Site:** High **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
								Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
		1.0+	5.0+	9.0+	13.0+	17.0+					Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	6	1,201	57	10	--	--	18	560	119	243	50	283
15	4	615	64	12	3	--	23	729	232	377	165	920
20	8	768	197	41	11	3	77	2,109	250	1,493	585	3,368
25	7	1,060	239	62	9	1	85	2,479	251	1,506	526	2,972
30	22	913	222	77	24	5	100	2,905	169	1,975	939	5,389
35	29	872	232	88	26	5	111	3,319	132	2,342	1,119	6,406
40	45	746	232	95	33	8	118	3,486	119	2,523	1,337	7,631
45	40	744	231	91	35	11	120	3,660	134	2,607	1,395	7,989
50	45	645	220	90	35	11	118	3,470	100	2,492	1,344	7,712
55	37	668	206	90	43	15	125	4,073	149	3,014	1,927	11,052
60	26	589	192	95	45	18	127	4,090	169	3,034	2,054	11,808
65	19	621	205	89	41	14	121	3,726	171	2,737	1,599	9,207
70	13	711	194	95	49	16	129	4,088	165	3,028	2,055	11,827
75	8	534	191	102	53	22	144	4,839	323	3,726	2,705	15,645
80	16	460	172	91	51	23	133	4,414	220	3,159	2,273	13,171

Table 21b.--Average empirical yields of forest biomass for fully stocked stands

Type: Oak-hickory **Site:** High **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	22.5	4.5	14.1	6.4	--	--	3.7	--	1.9	6.6	7.5	2.9
15	28.3	8.9	21.5	11.1	5.2	--	3.9	--	4.8	5.9	11.8	1.9
20	79.3	8.7	70.7	39.6	22.7	11.1	3.7	0.7	8.9	33.0	15.3	17.8
25	94.5	9.5	74.6	44.0	13.8	2.7	12.4	1.2	21.0	21.7	26.3	11.9
30	110.8	6.1	97.0	71.2	38.0	15.1	8.3	.4	23.5	39.6	23.9	15.1
35	127.4	4.9	115.9	87.2	46.8	17.5	9.1	.8	24.9	36.1	41.2	15.4
40	133.2	4.5	122.7	96.7	55.9	21.8	12.0	.5	24.5	37.3	42.8	16.1
45	140.4	5.3	129.1	101.3	64.6	30.1	10.7	.1	27.3	39.9	48.5	14.0
50	134.2	3.8	125.3	99.4	62.5	28.8	6.1	3.3	21.8	34.1	45.2	23.6
55	158.1	5.5	147.8	125.5	90.0	48.7	12.5	1.2	29.7	38.5	52.1	24.2
60	158.8	6.3	150.6	132.9	97.6	56.5	10.8	.1	35.4	35.4	51.8	25.3
65	144.6	6.1	135.8	113.3	80.0	42.2	6.0	2.6	18.3	40.8	52.0	24.8
70	159.9	6.2	150.7	133.7	103.3	51.1	11.5	.1	26.1	40.6	51.9	29.7
75	189.2	12.9	184.1	167.5	130.3	79.4	6.8	1.1	49.6	41.9	61.5	28.2
80	174.8	8.7	168.1	155.1	126.7	82.9	8.0	1.0	17.7	31.9	83.5	32.7

Table 22a.--Average empirical yields of timber for fully stocked stands

Type: Oak-hickory **Site:** Medium **Region:** Coastal Plain

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
								Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
		1.0+	5.0+	9.0+	13.0+	17.0+					Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	13	721	36	--	--	--	8	299	69	104	--	--
15	16	1,105	87	15	--	--	25	903	117	350	54	300
20	5	1,385	77	11	3	--	22	915	127	314	84	465
25	11	1,171	213	40	7	2	69	2,120	173	1,133	326	1,818
30	20	1,181	214	47	10	4	78	2,343	172	1,400	515	2,920
35	13	1,203	213	58	15	3	84	2,723	184	1,577	531	3,032
40	22	797	223	76	21	7	101	2,850	194	1,805	826	4,732
45	11	903	203	68	20	5	92	2,815	199	1,883	762	4,405
50	15	986	254	87	26	6	116	3,440	256	2,337	1,001	5,772
55	18	661	197	86	34	11	112	3,283	134	2,251	1,309	7,543
60	13	663	209	92	32	12	120	3,708	165	2,645	1,514	8,746
65	9	716	207	94	35	7	114	3,573	142	2,566	1,395	8,072
70	9	456	165	87	45	21	124	4,082	441	2,929	2,050	11,972
75	9	922	185	76	34	12	110	3,745	273	2,656	1,631	9,431
80	5	654	182	82	45	18	130	4,069	333	3,084	2,271	12,828

Table 22b.--Average empirical yields of forest biomass for fully stocked stands

Type: Oak-hickory **Site:** Medium **Region:** Coastal Plain

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	12.1	2.8	5.5	--	--	--	2.3	--	1.9	2.3	4.6	1.0
15	36.1	4.4	20.6	8.1	--	--	3.2	0.2	7.2	4.7	15.6	5.1
20	38.2	5.1	16.8	7.6	2.4	--	4.8	--	8.3	2.8	19.4	2.9
25	82.5	6.4	63.1	30.5	11.1	3.6	9.7	--	18.2	13.4	36.3	4.8
30	91.1	6.7	74.3	42.5	19.7	11.7	9.8	.2	16.5	12.2	44.0	8.4
35	105.9	6.4	85.3	52.0	24.5	9.6	6.3	--	19.7	21.8	41.9	16.2
40	108.7	6.2	97.4	69.8	35.7	18.7	8.8	.3	19.9	16.7	46.4	16.7
45	112.7	8.1	100.7	69.3	34.7	13.1	8.2	.5	14.4	8.2	70.3	11.1
50	135.2	10.5	122.7	86.1	43.8	16.6	6.6	.5	21.8	15.2	77.2	14.0
55	127.9	5.3	120.2	99.3	64.7	31.1	11.5	.2	20.5	25.2	54.9	15.8
60	144.7	6.2	135.4	111.7	70.2	38.6	8.1	--	22.6	24.2	68.5	21.2
65	141.8	5.9	132.4	110.3	67.2	26.3	6.1	.5	30.4	18.3	57.5	28.9
70	164.6	18.0	159.9	144.9	114.3	73.8	5.3	--	16.3	15.9	106.5	20.5
75	151.7	11.6	139.7	116.3	82.4	44.1	9.1	1.0	17.3	11.8	90.1	22.3
80	155.7	16.2	147.9	130.5	106.2	66.1	11.1	18.4	31.7	21.2	32.8	40.5

Table 23a.--Average empirical yields of timber for fully stocked stands

Type: Oak-hickory **Site:** High **Region:** Coastal Plain

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
		1.0+	5.0+	9.0+	13.0+	17.0+		Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
											Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	3	1,135	42	8	--	--	15	548	140	278	88	490
15	2	393	42	11	3	--	15	469	410	182	68	382
20	1	766	165	17	12	3	60	1,854	--	1,285	587	3,278
25	1	1,054	276	31	--	--	75	2,741	--	1,459	384	2,155
30	6	1,135	206	71	29	7	99	2,913	394	1,952	1,036	5,929
35	5	1,098	181	72	31	11	100	3,167	195	2,102	1,188	6,796
40	7	780	206	98	45	12	127	3,833	266	2,772	1,713	9,720
45	7	695	235	88	32	14	116	3,666	397	2,504	1,343	7,667
50	3	474	221	101	25	8	121	3,439	263	2,555	1,347	7,576
55	8	629	206	105	50	14	135	4,555	375	3,397	2,221	12,703
60	4	593	203	96	34	11	120	3,809	351	2,832	1,891	10,784
65	1	227	227	116	76	51	188	5,945	--	4,477	3,586	20,704
70	2	595	194	81	45	12	116	3,412	350	2,432	1,629	9,413
75	3	709	182	113	55	25	151	5,422	598	4,122	3,097	17,785
80	3	408	141	77	53	26	139	4,611	880	3,124	2,578	14,809

Table 23b.--Average empirical yields of forest biomass for fully stocked stands

Type: Oak-hickory **Site:** High **Region:** Coastal Plain

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	22.2	5.5	13.7	6.2	--	--	4.6	--	1.4	3.9	12.3	--
15	18.4	16.1	12.8	7.5	3.4	--	3.1	--	5.1	2.5	7.5	0.1
20	72.0	--	64.2	29.2	24.6	9.7	12.5	--	25.9	--	28.8	4.9
25	110.7	--	79.0	25.4	--	--	8.0	--	23.6	0.1	79.0	--
30	110.2	13.5	94.8	70.8	42.9	18.5	12.2	--	35.6	34.0	21.3	7.1
35	125.1	7.2	114.0	89.0	60.6	28.1	10.4	--	31.0	11.2	64.4	8.0
40	149.4	11.4	139.0	116.8	80.8	35.4	19.6	--	27.3	15.5	85.2	1.9
45	142.7	16.5	130.7	103.8	65.0	36.9	11.6	0.8	31.1	32.2	54.4	12.7
50	128.9	10.7	124.3	96.3	41.6	21.0	20.7	--	31.1	12.0	61.9	3.3
55	175.3	13.2	166.2	143.9	102.6	46.3	15.1	2.0	61.0	29.5	57.9	9.7
60	147.6	11.9	139.5	120.7	81.7	46.1	15.9	--	52.1	12.0	60.7	6.9
65	219.5	--	219.5	201.0	179.7	147.3	--	--	48.8	145.0	15.9	9.8
70	134.6	11.0	129.5	110.5	87.1	42.8	7.6	--	28.9	11.4	46.8	39.9
75	210.9	28.1	204.8	192.0	146.1	91.8	12.9	2.9	93.4	19.2	72.5	10.1
80	182.1	36.4	178.2	166.5	145.8	103.6	20.0	--	43.8	10.3	99.2	8.9

Table 24a.--Average empirical yields of timber for fully stocked stands

Type: Oak-hickory **Site:** Medium **Region:** Piedmont

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
								Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
		1.0+	5.0+	9.0+	13.0+	17.0+					Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	9	1,010	37	--	--	--	8	391	142	101	--	--
15	19	1,205	105	10	--	--	27	972	175	357	35	199
20	9	1,683	140	30	6	--	45	1,740	113	682	187	1,078
25	18	1,465	192	39	5	1	65	2,075	72	1,119	272	1,546
30	28	1,354	224	40	8	2	74	2,283	88	1,272	307	1,758
35	24	1,137	202	53	12	3	77	2,272	147	1,356	502	2,873
40	41	917	240	76	19	3	99	2,919	97	1,934	668	3,865
45	43	860	238	81	23	4	104	3,099	127	2,067	836	4,796
50	36	836	221	75	20	4	98	2,919	101	1,963	785	4,542
55	26	760	203	84	30	9	107	3,182	90	2,239	1,127	6,521
60	29	600	208	92	33	8	113	3,306	129	2,383	1,234	7,142
65	13	603	188	87	38	10	112	3,325	130	2,437	1,409	8,212
70	30	599	176	99	40	12	115	3,548	176	2,568	1,532	8,892
75	11	562	180	84	43	14	114	3,604	225	2,571	1,588	9,225
80	9	588	161	95	50	19	128	4,008	231	2,915	1,925	11,265

Table 24b.--Average empirical yields of forest biomass for fully stocked stands

Type: Oak-hickory **Site:** Medium **Region:** Piedmont

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	15.9	5.7	6.6	--	--	--	2.8	--	1.0	1.2	8.5	2.3
15	37.2	6.6	21.6	6.4	--	--	3.8	1.4	6.3	11.1	9.5	5.1
20	67.9	3.9	38.2	20.4	7.5	--	5.0	--	3.8	18.9	30.4	9.8
25	81.2	3.0	58.3	27.9	8.1	3.1	9.2	1.0	13.4	12.1	30.2	15.3
30	90.1	3.4	68.4	32.4	12.3	4.9	10.1	0.7	8.4	11.0	47.3	12.6
35	88.5	5.5	71.6	44.5	18.9	6.6	7.5	.4	13.2	18.4	35.5	13.5
40	116.2	3.9	102.1	68.4	30.3	9.0	5.9	.4	13.1	18.1	60.7	17.9
45	122.0	5.1	108.1	76.3	36.8	11.1	8.9	1.8	13.2	19.6	61.7	16.9
50	116.4	4.1	102.2	72.2	35.5	13.2	7.7	1.2	6.6	16.2	67.2	17.6
55	127.2	3.6	117.4	93.1	56.2	26.0	8.2	.9	7.9	19.4	75.5	15.3
60	131.7	5.0	123.9	100.4	60.2	24.0	6.8	1.9	7.5	20.5	76.4	18.6
65	133.9	5.5	128.5	109.2	74.0	34.4	5.3	.2	6.7	23.1	73.5	25.2
70	142.0	6.9	133.8	118.0	78.5	35.7	5.9	1.2	12.8	17.8	76.8	27.5
75	145.4	9.4	135.6	116.6	88.0	46.1	4.8	.9	7.2	29.6	75.4	27.4
80	164.2	9.6	158.1	144.2	113.9	63.8	3.5	.3	11.4	12.7	112.7	23.6

Table 25a.--Average empirical yields of timber for fully stocked stands

Type: Oak-hickory **Site:** High **Region:** Piedmont

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
		1.0+	5.0+	9.0+	13.0+	17.0+		Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
											Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	2	1,778	36	--	--	--	8	363	145	52	--	--
15	1	970	70	17	8	--	30	1,128	--	750	450	2,477
20	5	630	217	46	12	5	88	2,239	400	1,647	647	3,754
25	3	1,163	322	69	11	2	111	2,878	399	1,838	498	2,837
30	8	825	239	75	18	6	101	2,856	183	1,893	856	4,910
35	19	800	243	88	25	4	111	3,251	125	2,328	1,074	6,161
40	26	774	231	93	29	5	112	3,217	127	2,324	1,126	6,426
45	25	705	222	90	37	11	121	3,625	157	2,588	1,395	8,013
50	24	588	224	88	37	11	120	3,486	149	2,563	1,404	8,109
55	19	722	203	82	41	16	119	3,823	215	2,809	1,834	10,542
60	10	568	202	99	47	18	129	4,022	321	2,981	1,948	11,200
65	12	665	196	84	35	13	115	3,581	118	2,644	1,523	8,755
70	7	687	199	97	51	18	135	4,257	216	3,227	2,247	12,868
75	3	511	191	103	55	21	144	4,586	513	3,610	2,657	15,405
80	6	516	192	99	50	23	134	4,407	184	3,309	2,258	13,074

Table 25b.--Average empirical yields of forest biomass for fully stocked stands

Type: Oak-hickory **Site:** High **Region:** Piedmont

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	14.9	5.5	2.7	--	--	--	3.1	--	3.5	3.2	4.0	1.0
15	41.8	--	33.9	21.4	13.8	--	9.3	--	8.8	11.8	9.6	2.3
20	84.1	13.9	77.0	44.1	25.1	15.9	1.0	--	5.6	39.9	18.3	19.3
25	107.6	12.7	88.4	46.2	15.7	6.3	11.9	2.8	40.3	26.7	11.2	14.7
30	110.1	6.9	96.4	68.8	36.1	18.9	7.5	1.0	26.9	27.1	31.8	15.8
35	124.9	5.0	114.1	84.5	44.1	13.7	9.2	0.3	24.8	31.1	44.5	14.9
40	122.7	4.8	111.5	85.7	44.8	13.4	11.4	--	23.2	34.2	37.0	16.9
45	139.4	6.1	128.6	100.9	65.7	29.8	9.0	--	30.4	36.2	49.9	13.9
50	135.7	5.5	128.8	102.6	67.8	30.8	5.1	.7	29.0	32.0	43.0	25.9
55	148.6	8.0	136.7	115.2	84.8	47.8	12.0	--	22.0	40.4	50.1	24.1
60	158.1	12.5	149.8	131.1	94.3	52.5	11.3	--	24.3	33.0	52.1	37.4
65	139.0	4.3	129.1	106.8	72.4	40.1	9.3	--	24.3	32.3	46.4	26.7
70	164.4	7.8	154.6	137.9	109.3	56.4	14.7	--	31.4	52.0	31.6	34.6
75	178.6	17.7	173.5	157.0	123.6	73.1	5.2	--	11.1	77.9	47.7	36.7
80	174.3	5.6	165.5	151.3	117.9	73.1	9.8	--	6.6	42.1	71.4	44.4

Table 26a.--Average empirical yields of timber for fully stocked stands

Type: Oak-hickory **Site:** Medium **Region:** Mountain

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
		1.0+	5.0+	9.0+	13.0+	17.0+		Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
											Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	5	1,276	20	--	--	--	5	404	122	57	--	--
15	4	1,299	50	6	--	--	14	656	174	176	35	200
20	--	--	--	--	--	--	--	--	--	--	--	--
25	2	1,535	184	45	14	4	71	2,239	846	1,143	543	3,000
30	7	1,267	232	51	7	2	78	2,079	128	1,203	293	1,666
35	7	1,122	251	58	10	2	94	2,709	290	1,676	528	3,010
40	17	800	233	75	18	4	98	2,748	121	1,838	669	3,862
45	19	879	266	69	20	5	105	2,871	130	1,865	628	3,607
50	16	773	218	75	18	6	99	2,864	113	1,912	706	4,084
55	16	668	249	86	25	4	112	3,136	164	2,063	824	4,752
60	17	772	221	92	31	8	112	3,334	146	2,222	1,044	6,005
65	15	632	219	85	27	8	109	3,105	154	2,187	992	5,794
70	16	710	203	88	38	13	116	3,565	111	2,516	1,419	8,209
75	6	760	230	90	35	11	117	3,291	280	2,250	1,060	6,185
80	13	604	211	84	36	14	120	3,519	190	2,503	1,508	8,626

Table 26b.--Average empirical yields of forest biomass for fully stocked stands

Type: Oak-hickory **Site:** Medium **Region:** Mountain

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	16.6	5.1	2.7	--	--	--	1.6	0.5	0.7	3.5	4.5	5.7
15	25.6	6.6	11.4	3.9	--	--	0.7	--	.2	11.2	7.4	6.0
20	--	--	--	--	--	--	--	--	--	--	--	--
25	84.8	31.5	64.3	37.4	22.0	9.6	8.4	13.1	--	20.9	28.7	13.7
30	82.6	5.2	62.7	32.6	8.3	2.7	9.2	--	4.2	7.9	41.4	19.8
35	106.4	12.1	88.0	49.0	16.6	6.6	2.8	3.6	.4	23.4	49.5	26.6
40	108.7	4.9	98.0	65.8	30.5	13.3	2.8	2.2	2.3	29.6	51.4	20.5
45	112.0	5.1	100.7	60.2	29.4	10.5	4.6	1.5	1.8	25.3	56.5	22.3
50	114.8	4.6	103.2	70.6	33.4	16.9	2.6	3.0	2.6	18.7	65.4	22.5
55	124.9	6.7	113.5	80.3	40.2	11.4	7.5	3.3	1.9	17.4	75.9	19.0
60	133.7	5.6	121.2	96.1	55.9	22.0	2.2	7.7	1.6	15.9	78.3	28.0
65	124.9	6.1	117.7	91.0	52.7	23.3	3.2	1.9	1.5	12.5	77.1	28.6
70	141.6	4.5	130.8	109.4	74.6	38.4	3.0	6.2	1.8	27.6	77.7	25.3
75	133.2	12.0	125.7	98.5	64.4	29.5	.7	2.2	1.3	11.4	89.8	27.8
80	138.1	7.0	128.9	105.3	72.4	40.7	.5	13.1	.2	29.2	72.6	22.4

Table 27a.--Average empirical yields of timber for fully stocked stands

Type: Oak-hickory **Site:** High **Region:** Mountain

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
		1.0+	5.0+	9.0+	13.0+	17.0+		Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
											Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	1	248	148	35	--	--	49	991	--	519	39	228
15	1	704	103	11	--	--	30	850	--	395	75	440
20	1	1,481	81	19	19	--	38	1,735	--	997	615	3,505
25	2	881	161	66	9	--	66	2,043	456	1,222	525	2,956
30	4	714	249	109	38	6	123	3,604	297	2,619	1,247	7,207
35	3	656	222	103	14	3	105	3,187	315	2,263	891	5,074
40	6	567	240	113	36	11	129	4,030	521	3,042	1,691	9,755
45	3	823	289	108	35	--	126	3,530	635	2,546	1,023	5,889
50	12	829	217	92	28	8	109	3,272	153	2,249	1,112	6,316
55	5	459	206	102	43	12	133	4,181	207	3,097	1,747	10,104
60	5	501	161	78	51	19	122	3,912	290	2,797	1,938	11,283
65	6	599	218	93	46	10	124	3,645	310	2,632	1,420	8,195
70	1	693	193	112	65	31	154	4,640	--	3,534	2,605	15,164
75	--	--	--	--	--	--	--	--	--	--	--	--
80	3	456	202	99	49	18	134	3,875	510	2,444	1,530	8,902

Table 27b.--Average empiric' yields of forest biomass for fully stocked stands

Type: Oak-hickory **Site:** High **Region:** Mountain

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	38.6	--	37.8	19.5	--	--	2.1	--	--	21.4	--	15.2
15	34.6	--	26.4	8.0	--	--	--	--	0.2	6.8	22.6	5.1
20	64.4	--	43.6	31.6	31.6	--	--	5.6	--	41.3	--	17.4
25	78.3	22.7	60.0	45.7	13.3	--	11.2	--	--	25.9	24.4	16.8
30	137.2	10.7	124.8	99.4	51.8	12.9	3.3	--	1.8	76.4	21.6	34.0
35	119.4	11.8	105.2	79.9	23.1	8.4	1.6	5.2	.7	74.1	--	37.8
40	153.3	18.3	146.5	124.9	71.2	31.4	2.9	3.6	2.0	77.6	33.5	33.8
45	131.2	24.9	116.2	86.4	39.1	--	6.5	--	3.6	72.4	25.1	23.6
50	127.4	6.1	114.0	89.0	50.9	23.1	2.7	11.0	1.8	33.3	53.5	25.1
55	165.3	10.8	158.9	136.5	91.7	42.7	--	5.6	1.0	53.3	38.0	67.4
60	151.5	11.2	141.6	123.9	102.0	53.0	--	--	.6	60.1	49.6	41.1
65	143.4	12.1	135.4	111.7	78.5	28.7	0.4	8.3	1.3	40.5	69.2	23.6
70	180.4	--	174.8	163.8	134.1	82.9	--	0.8	--	78.0	61.5	40.0
75	--	--	--	--	--	--	--	--	--	--	--	--
80	153.2	20.1	145.8	131.3	97.5	57.4	--	5.3	4.1	20.3	111.1	12.5

Table 28a.--Average empirical yields of timber for fully stocked stands

Type: Oak-gum-cypress **Site:** Medium **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
								Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
		1.0+	5.0+	9.0+	13.0+	17.0+					Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	7	1,202	22	--	--	--	5	350	104	85	--	--
15	7	1,520	27	6	--	--	9	796	225	117	38	197
20	16	2,294	191	29	3	--	52	2,096	226	746	189	991
25	23	2,020	246	46	10	3	85	2,797	237	1,340	445	2,449
30	46	1,566	293	59	13	4	103	3,233	191	1,714	550	3,067
35	62	1,264	308	80	21	6	117	3,421	144	1,959	733	4,098
40	87	1,052	312	96	29	8	136	3,801	128	2,351	1,016	5,668
45	82	973	299	102	28	7	134	3,812	147	2,411	1,042	5,843
50	110	975	304	110	32	9	145	4,052	123	2,530	1,194	6,677
55	79	872	275	111	40	10	145	4,126	142	2,680	1,351	7,616
60	108	886	296	122	41	11	155	4,530	135	3,014	1,603	8,955
65	70	843	310	133	50	15	171	4,800	170	3,225	1,864	10,410
70	63	877	280	139	56	18	174	5,126	216	3,462	2,104	11,788
75	49	877	293	129	55	18	173	4,950	208	3,271	1,928	10,817
80	48	879	280	131	58	21	176	5,062	246	3,468	2,188	12,267

Table 28b.--Average empirical yields of forest biomass for fully stocked stands

Type: Oak-gum-cypress **Site:** Medium **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	13.1	3.6	3.8	--	--	--	2.2	0.8	3.8	4.7	0.2	1.4
15	30.9	8.6	6.3	2.5	--	--	3.8	3.5	8.0	8.1	6.7	0.8
20	73.3	8.0	36.0	15.4	3.1	--	5.2	22.2	29.5	15.0	1.2	.2
25	98.7	8.4	66.6	34.6	16.5	9.0	7.9	19.9	38.3	22.7	7.5	2.3
30	113.3	6.7	86.3	46.8	20.7	10.1	5.8	13.4	46.4	29.7	12.6	5.3
35	118.1	4.6	97.4	61.6	30.6	12.7	6.3	18.9	46.3	31.0	11.2	4.3
40	131.4	4.7	115.5	79.1	43.5	20.1	5.1	23.8	54.9	28.7	9.4	9.5
45	132.9	5.2	117.8	83.2	44.2	18.6	4.3	24.8	57.9	20.4	18.9	6.6
50	141.8	4.3	126.6	94.0	51.2	22.5	5.2	23.8	59.0	28.0	13.6	12.1
55	143.9	4.9	130.0	101.1	62.1	25.5	3.4	24.6	67.5	21.7	13.0	13.6
60	159.5	4.9	146.3	115.5	68.8	30.6	5.9	35.0	61.0	25.7	21.2	10.7
65	170.4	6.3	158.7	128.8	82.5	38.8	3.2	41.8	66.1	24.2	21.5	13.5
70	180.9	7.5	169.1	144.2	96.6	50.0	2.4	41.8	70.8	24.8	21.2	19.9
75	174.0	7.5	161.6	134.0	92.1	46.5	1.5	37.3	78.1	25.0	14.2	17.9
80	181.2	9.6	170.6	145.5	103.9	58.4	3.1	39.0	82.9	24.5	21.3	10.5

Table 29a.--Average empirical yields of timber for fully stocked stands

Type: Oak-gum-cypress **Site:** High **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
		1.0+	5.0+	9.0+	13.0+	17.0+		Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
											Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	6	1,499	18	13	--	--	9	597	162	198	63	346
15	3	1,143	177	26	4	--	46	1,559	1,056	811	225	1,187
20	2	1,443	213	41	13	6	83	2,266	318	1,414	738	4,266
25	6	1,319	272	61	22	5	103	3,198	200	2,013	744	4,177
30	18	1,203	278	87	28	6	118	3,630	192	2,290	1,032	5,895
35	34	765	249	98	28	8	123	3,704	144	2,552	1,215	6,873
40	45	799	262	115	38	12	144	4,306	209	2,935	1,582	8,966
45	42	812	244	108	43	12	139	4,325	177	2,997	1,653	9,469
50	53	765	251	115	47	14	148	4,614	160	3,255	1,940	11,033
55	18	737	210	108	49	17	139	4,338	203	3,105	1,937	11,050
60	40	753	265	117	51	15	156	4,737	190	3,298	2,020	11,486
65	21	674	215	110	55	19	153	4,846	305	3,345	2,257	12,978
70	22	738	257	130	63	22	174	5,545	394	3,942	2,682	15,154
75	13	780	235	125	63	31	182	5,729	650	4,050	2,979	16,708
80	19	596	201	99	54	29	159	4,974	321	3,474	2,603	14,747

Table 29b.--Average empirical yields of forest biomass for fully stocked stands

Type: Oak-gum-cypress **Site:** High **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	23.4	6.0	8.9	7.8	--	--	2.6	--	8.2	7.1	5.0	0.5
15	58.9	39.0	39.2	16.5	5.2	--	10.5	--	30.2	9.4	8.6	.1
20	84.8	6.0	69.4	45.0	26.4	17.0	3.6	--	13.8	33.5	28.7	5.1
25	118.8	8.0	96.7	54.3	30.3	11.9	12.9	--	57.3	19.5	26.2	2.9
30	130.1	7.2	108.3	77.2	42.4	14.7	7.4	0.3	54.5	49.0	13.6	5.3
35	133.6	5.1	121.4	91.9	47.0	21.2	9.3	5.9	51.3	42.3	16.4	8.4
40	153.7	7.6	142.1	115.2	67.3	34.7	5.7	12.4	71.4	40.2	13.6	10.4
45	159.2	6.5	147.3	119.9	77.2	34.8	6.9	3.9	65.7	36.1	35.3	11.4
50	167.0	6.1	155.7	130.9	85.9	41.2	8.5	10.8	68.5	42.2	26.8	10.2
55	159.6	7.9	149.1	128.7	91.5	47.0	11.9	4.6	65.4	36.7	32.5	8.5
60	173.0	6.9	163.4	137.2	96.3	47.3	7.9	11.7	77.8	35.4	28.1	12.1
65	177.4	10.3	169.2	149.9	113.5	63.6	5.3	6.8	77.5	27.3	43.8	16.6
70	199.2	14.3	190.8	167.9	124.6	68.0	7.0	28.3	108.7	23.0	14.2	18.0
75	214.0	27.4	203.9	182.9	144.7	102.1	7.5	38.4	99.0	28.1	26.4	14.6
80	187.4	14.3	178.0	160.3	135.0	99.0	3.4	24.2	93.0	32.7	24.3	9.9

Table 30a.--Average empirical yields of timber for fully stocked stands

Type: Natural yellow pine **Site:** All sites **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
								Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
		1.0+	5.0+	9.0+	13.0+	17.0+					Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	58	1,220	69	--	--	--	14	683	68	158	--	--
15	97	1,420	167	13	--	--	41	1,341	78	566	71	378
20	166	1,475	245	27	2	--	66	1,975	55	1,005	221	1,171
25	267	1,075	292	55	7	1	94	2,612	50	1,704	662	3,505
30	326	972	284	77	13	2	106	2,963	54	2,112	1,061	5,616
35	278	988	283	85	17	2	111	3,225	61	2,348	1,292	6,841
40	247	841	261	92	22	3	114	3,384	71	2,555	1,573	8,337
45	175	818	245	98	27	4	115	3,481	82	2,679	1,825	9,670
50	102	813	241	104	31	6	119	3,811	121	2,979	2,153	11,410
55	65	816	237	113	33	5	124	3,895	126	3,008	2,207	11,703
60	48	1,006	232	100	28	5	114	3,530	140	2,689	1,981	10,498
65	26	829	230	109	40	8	128	4,180	296	3,315	2,582	13,699
70	15	683	203	116	37	4	122	3,853	215	3,141	2,515	13,317
75	10	788	172	123	54	11	133	4,703	483	3,853	3,551	18,785
80	10	1,027	251	119	46	6	137	4,279	582	3,345	2,522	13,363

Table 30b.--Average empirical yields of forest biomass for fully stocked stands

Type: Natural yellow pine **Site:** All sites **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	25.0	2.5	9.3	--	--	--	22.6	0.2	0.5	0.6	0.6	0.5
15	49.3	2.8	28.6	5.3	--	--	44.4	.2	1.7	1.0	1.4	.5
20	73.0	2.0	49.4	13.7	2.2	--	64.7	.5	2.6	1.8	2.1	1.3
25	97.2	1.9	80.2	36.2	9.9	2.7	87.6	1.0	2.8	2.3	2.5	1.0
30	110.3	2.0	96.6	56.1	17.9	4.3	98.3	.6	4.3	2.9	2.9	1.3
35	119.7	2.3	105.8	66.8	23.4	4.6	106.2	.6	4.4	3.5	3.3	1.6
40	125.7	2.6	114.0	79.3	32.7	7.7	109.6	1.2	5.2	3.3	4.1	2.3
45	129.3	3.0	118.8	89.6	41.4	10.6	113.9	.7	5.0	4.0	4.2	1.5
50	141.8	4.5	131.0	103.5	52.1	14.5	124.1	1.2	5.5	4.1	4.2	2.6
55	143.9	4.4	133.1	108.3	51.5	12.6	123.1	1.1	6.3	4.4	5.7	3.4
60	130.9	5.2	118.2	93.8	47.5	14.6	110.7	.6	5.4	5.6	5.7	2.9
65	155.0	11.3	145.6	120.7	72.1	23.3	131.0	.4	5.5	4.9	9.9	3.3
70	145.5	8.7	138.0	119.2	58.1	10.3	132.4	.7	4.5	1.6	4.2	2.2
75	172.8	17.1	165.4	155.7	102.9	38.4	154.4	.3	7.1	4.2	2.3	4.5
80	156.3	20.3	145.5	120.3	71.2	16.0	124.2	10.0	4.6	11.4	3.3	2.8

Table 31a.--Average empirical yields of timber for fully stocked stands

Type: Planted yellow pine **Site:** All sites **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
								Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
		1.0+	5.0+	9.0+	13.0+	17.0+					Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	238	944	78	--	--	--	14	629	30	142	--	--
15	243	893	244	9	--	--	55	1,472	46	745	62	329
20	298	793	327	27	1	--	86	2,168	51	1,390	224	1,183
25	167	626	333	60	3	--	106	2,686	67	1,973	604	3,191
30	33	525	279	100	10	--	112	2,976	160	2,326	1,165	6,157
35	11	680	267	84	18	1	107	3,030	326	2,265	1,376	7,277
40	10	517	211	110	37	2	117	3,659	359	2,990	2,355	12,452
45	--	--	--	--	--	--	--	--	--	--	--	--
50	--	--	--	--	--	--	--	--	--	--	--	--
55	--	--	--	--	--	--	--	--	--	--	--	--
60	--	--	--	--	--	--	--	--	--	--	--	--
65	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 31b.--Average empirical yields of forest biomass for fully stocked stands

Type: Planted yellow pine **Site:** All sites **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	22.6	1.1	7.9	--	--	--	21.3	--	0.4	0.3	0.5	0.2
15	54.4	1.7	38.0	4.1	--	--	52.4	0.1	.4	.5	.8	.2
20	81.6	1.9	68.2	13.8	1.1	--	78.5	.1	.7	.5	1.6	.3
25	101.5	2.5	93.3	35.5	3.3	0.3	98.8	--	.9	.3	1.2	.2
30	111.5	5.8	105.0	64.3	12.0	.5	107.9	.7	1.7	.6	.3	.3
35	113.7	12.4	103.5	69.7	23.2	2.0	109.8	--	.8	.5	1.4	1.1
40	139.9	14.0	134.3	113.8	53.0	5.1	131.8	--	1.7	1.0	5.0	.3
45	--	--	--	--	--	--	--	--	--	--	--	--
50	--	--	--	--	--	--	--	--	--	--	--	--
55	--	--	--	--	--	--	--	--	--	--	--	--
60	--	--	--	--	--	--	--	--	--	--	--	--
65	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--

Table 32a.--Average empirical yields of timber for fully stocked stands

Type: Natural oak-pine **Site:** All sites **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
								Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
		1.0+	5.0+	9.0+	13.0+	17.0+					Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	23	939	39	--	--	--	9	433	72	112	--	--
15	25	1,338	97	13	--	--	26	951	100	388	74	397
20	36	1,591	203	30	4	--	61	1,984	100	995	257	1,412
25	39	1,361	205	38	9	1	68	2,014	124	1,106	406	2,188
30	73	1,172	246	60	16	4	92	2,672	105	1,729	806	4,368
35	75	1,095	235	66	17	4	95	2,807	107	1,797	896	4,878
40	83	1,032	229	69	19	5	97	2,913	97	1,953	1,028	5,592
45	73	944	236	78	24	7	107	3,155	90	2,189	1,219	6,693
50	67	958	241	90	26	7	114	3,477	114	2,415	1,393	7,591
55	49	875	212	81	28	7	106	3,268	142	2,315	1,390	7,617
60	47	943	230	85	30	8	112	3,462	148	2,342	1,460	7,965
65	22	994	202	84	34	10	114	3,549	217	2,442	1,705	9,353
70	31	746	221	86	37	15	124	3,900	194	2,877	2,126	11,667
75	11	788	181	85	38	9	107	3,332	219	2,410	1,784	9,721
80	13	969	217	93	37	11	121	3,897	331	2,805	1,919	10,537

Table 32b.--Average empirical yields of forest biomass for fully stocked stands

Type: Natural oak-pine **Site:** All sites **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	16.5	2.7	5.5	--	--	--	5.9	0.7	4.9	1.6	2.0	1.5
15	36.2	3.8	19.5	6.7	--	--	14.0	1.8	8.0	4.3	5.7	2.4
20	74.3	3.7	50.0	19.3	5.5	--	29.0	4.4	9.4	13.7	14.0	3.9
25	75.3	4.5	55.7	26.7	10.9	2.7	31.4	3.2	12.8	8.3	14.4	5.2
30	99.8	3.8	83.0	49.7	23.6	8.8	41.2	1.9	19.9	12.0	19.7	5.1
35	104.7	3.9	88.2	57.1	27.5	10.7	39.4	5.6	18.7	11.5	22.6	6.9
40	109.6	3.6	94.1	63.4	31.7	12.6	41.7	4.2	14.9	12.9	29.2	6.7
45	118.6	3.3	105.5	75.4	42.5	19.3	43.0	4.9	17.9	14.1	30.9	7.9
50	129.3	4.2	114.3	85.3	45.1	18.5	46.7	7.0	25.0	16.3	25.1	9.3
55	123.6	5.2	110.6	84.8	49.1	19.9	41.2	6.5	14.9	16.9	34.9	9.2
60	129.9	5.3	115.4	88.1	52.7	21.5	48.2	5.1	21.9	13.2	32.1	9.4
65	134.6	8.3	119.4	96.7	64.9	31.8	44.1	11.1	19.8	14.3	39.0	6.3
70	147.4	7.0	137.1	113.3	81.2	48.6	53.8	5.0	24.6	20.2	34.7	9.0
75	127.8	8.2	119.0	101.3	69.4	26.4	51.1	4.7	12.0	11.2	38.5	10.3
80	145.0	12.7	131.6	108.8	72.1	34.4	51.0	8.0	22.9	27.4	28.8	6.9

Table 33a.--Average empirical yields of timber for fully stocked stands

Type: Oak-hickory **Site:** All sites **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
		1.0+	5.0+	9.0+	13.0+	17.0+		Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
											Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	34	967	35	--	--	--	8	359	53	97	--	--
15	50	1,160	86	11	--	--	23	857	86	306	40	227
20	24	1,505	119	21	5	--	38	1,434	107	579	153	872
25	43	1,345	199	43	7	2	68	2,125	77	1,159	339	1,910
30	85	1,185	217	50	12	3	79	2,377	79	1,422	494	2,825
35	76	1,036	220	66	17	4	92	2,764	97	1,781	732	4,188
40	132	828	232	79	23	5	104	3,032	71	2,051	896	5,142
45	121	828	236	79	25	6	107	3,149	81	2,135	940	5,392
50	121	774	226	82	25	7	107	3,150	66	2,165	985	5,674
55	109	695	216	85	33	10	114	3,440	81	2,427	1,332	7,656
60	91	680	206	91	35	11	116	3,543	86	2,515	1,426	8,218
65	65	643	205	85	33	10	111	3,300	90	2,361	1,263	7,311
70	79	635	185	91	39	13	116	3,588	103	2,581	1,558	9,032
75	39	691	199	90	39	14	120	3,783	149	2,708	1,636	9,486
80	45	568	185	90	45	18	128	3,973	126	2,856	1,908	11,010

Table 33b.--Average empirical yields of forest biomass for fully stocked stands

Type: Oak-hickory **Site:** All sites **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	14.6	2.1	5.4	--	--	--	2.5	0.1	1.5	2.5	6.1	1.9
15	33.5	3.2	18.5	6.4	--	--	3.0	.6	5.3	8.7	11.6	4.4
20	56.4	3.9	31.2	14.9	5.8	--	4.3	.2	4.9	15.4	24.5	7.1
25	82.7	2.9	61.4	32.0	11.1	4.0	9.5	1.6	13.9	14.4	32.4	10.8
30	92.6	2.9	73.9	42.6	19.4	8.5	8.8	.4	13.4	18.4	39.2	12.5
35	107.0	3.6	91.5	61.3	29.8	11.1	7.5	.8	17.4	25.5	40.2	15.6
40	118.0	2.6	105.5	75.3	38.9	15.3	7.8	.6	16.1	25.3	51.0	17.1
45	122.9	3.1	110.5	78.6	43.0	17.1	8.4	1.0	15.4	25.4	56.8	15.9
50	124.0	2.6	112.3	82.4	45.1	19.4	6.4	2.1	13.7	22.6	60.1	19.1
55	135.3	3.0	125.6	99.7	63.8	30.9	10.6	1.4	16.3	25.3	63.5	18.2
60	139.8	3.2	129.9	107.3	69.0	33.9	7.2	2.4	16.1	23.7	67.8	22.5
65	130.8	3.4	122.7	99.5	64.1	30.1	5.0	2.0	11.6	23.2	63.7	25.2
70	142.9	4.1	134.3	116.1	80.9	40.5	5.9	2.1	12.8	22.3	75.5	24.4
75	151.6	5.9	142.5	120.9	84.9	45.4	6.0	1.1	16.6	22.1	80.9	24.9
80	157.6	5.1	150.1	132.8	102.0	61.7	5.1	6.2	12.2	24.9	81.0	28.2

Table 34a.--Average empirical yields of timber for fully stocked stands

Type: Oak-gum-cypress **Site:** All sites **Region:** Southeast

Stand age (years)	Sample plots	Live trees per acre, by d.b.h. class (inches)					Basal area per acre, trees 5.0+ inches	Volume per acre				
								Total aboveground trees 1.0+	Standard error	Growing stock	Sawtimber	
		1.0+	5.0+	9.0+	13.0+	17.0+					Saw-log portion	International ¼-inch rule
		Number					Square feet	Cubic feet				Board feet
10	13	1,343	15	--	--	--	3	374	121	52	--	--
15	14	1,614	60	6	--	--	14	1,001	197	190	49	257
20	27	2,511	159	25	4	--	45	1,927	194	647	188	986
25	42	2,045	231	43	11	4	80	2,774	192	1,321	474	2,607
30	84	1,643	292	62	15	4	103	3,213	135	1,723	599	3,360
35	106	1,123	289	82	22	6	117	3,448	106	2,096	855	4,796
40	153	1,050	293	96	29	8	133	3,828	112	2,395	1,108	6,210
45	133	962	276	101	32	8	132	3,874	117	2,519	1,196	6,761
50	182	941	292	109	35	10	144	4,138	96	2,679	1,370	7,700
55	116	880	273	108	39	10	142	4,075	117	2,652	1,369	7,713
60	158	861	286	119	43	12	154	4,537	108	3,043	1,690	9,476
65	104	825	294	121	47	14	162	4,634	139	3,107	1,828	10,264
70	99	917	287	130	54	18	170	5,023	178	3,349	2,056	11,530
75	69	915	282	128	53	19	171	4,986	208	3,327	2,019	11,314
80	82	889	270	121	52	21	168	4,864	185	3,266	2,101	11,778

Table 34b.--Average empirical yields of forest biomass for fully stocked stands

Type: Oak-gum-cypress **Site:** All sites **Region:** Southeast

Stand age (years)	Total 1.0+	Standard error	D.b.h. class (inches)				Species group					
			5.0+	9.0+	13.0+	17.0+	Yellow pines	Other softwood	Gums	Soft hardwood	Oaks	Hard hardwood
	Green tons per acre											
10	14.3	4.6	2.3	--	--	--	1.5	0.6	7.4	3.5	0.6	0.8
15	37.6	7.2	9.6	3.1	--	--	3.9	1.9	17.2	9.7	4.5	.5
20	67.6	6.6	31.8	14.4	3.9	--	4.0	22.7	25.0	13.6	2.3	.1
25	98.3	6.7	64.8	34.6	17.4	8.8	7.9	16.8	39.4	23.7	8.7	1.8
30	111.9	4.8	84.3	48.5	22.7	9.4	5.0	14.1	48.0	29.9	10.2	4.6
35	120.3	3.6	101.9	68.2	33.9	14.6	7.4	16.9	46.1	32.5	11.9	5.6
40	133.3	4.1	117.0	84.0	46.4	22.3	4.8	22.9	56.4	30.8	9.8	8.5
45	137.5	4.3	123.2	91.7	52.6	22.8	4.9	19.0	58.2	24.3	23.0	8.1
50	145.7	3.5	131.3	100.8	58.8	26.5	6.2	23.0	58.6	30.3	16.2	11.4
55	142.4	4.2	128.8	100.4	61.9	27.2	4.7	26.3	61.7	23.3	15.0	11.5
60	161.1	4.0	148.7	119.2	74.6	34.5	6.3	30.2	64.0	27.9	21.9	10.9
65	164.5	5.2	153.5	124.3	82.5	41.0	3.3	37.8	62.7	23.0	24.6	13.1
70	177.6	6.4	165.3	138.5	94.8	49.4	3.5	40.8	74.7	22.1	17.8	18.8
75	177.0	8.0	164.1	137.5	95.4	53.2	2.6	38.1	80.4	24.3	15.5	16.0
80	174.4	7.4	162.9	138.4	99.8	60.9	3.5	40.5	79.0	23.6	18.1	9.9

McClure, Joe P.; Knight, Herbert A.
Empricial yields of timber and forest biomass in the Southeast. Res. Pap. SE-245. Asheville, NC: U.S. Department of Argiculture, Forest Service, Southeastern Forest Experiment Station; 1984. 75 p.

Measurements and classifications recorded at 24,775 Forest Survey plots established randomly throughout the Southeast comprise a vast source of information on timber stand development. Raw, empricial yield tables developed from this source are reported for major forest types in the Region. These tables also serve as guides to yields of forest biomass by tree size and species group.

KEYWORDS: Southeast, yield tables, forest biomass.

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United States
Department of
Agriculture

Forest Service

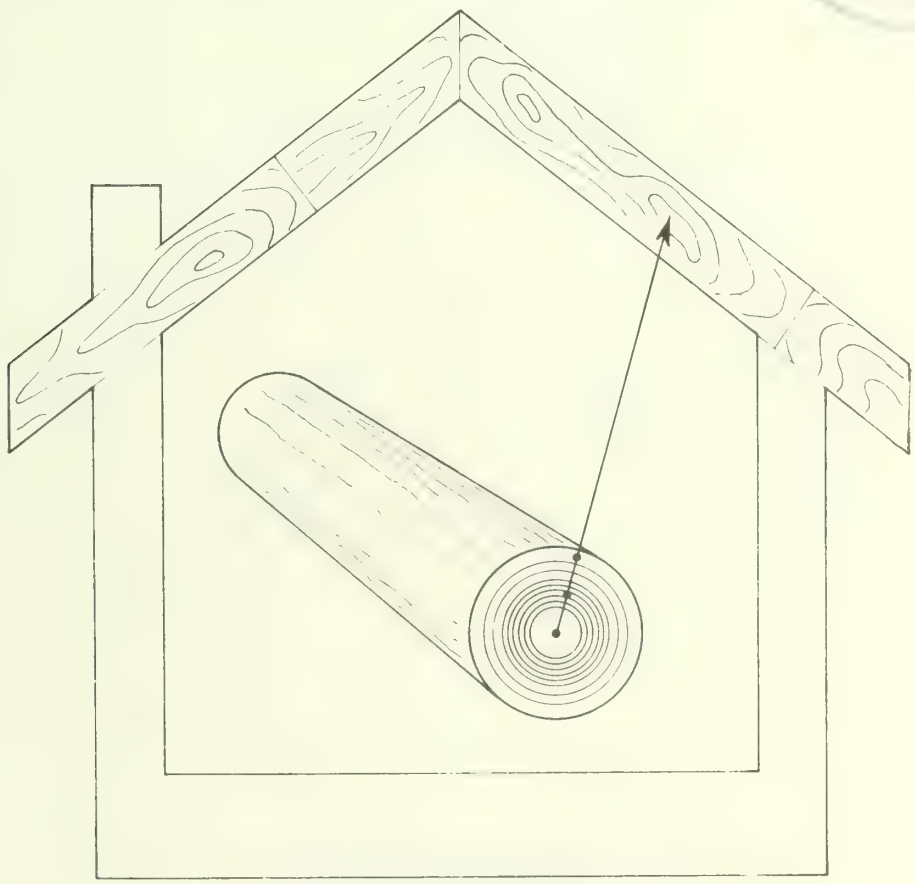
In Cooperation With

United States
Department of
Housing and
Urban Development

Research Paper SE-246

Tensile Strength of Composite Truss Lumber as Affected by Veneer Species and Member Width

Robert H. McAlister



COM-PLY® Report 27

ABSTRACT

One hundred and twenty pieces of composite truss lumber made with southern pine and yellow-poplar veneers of varying grades and in nominal widths from 2 x 4 to 2 x 10 were tested in tension. The modulus of elasticity (MOE) for both species was about 1.3 million psi. There were no differences in tensile strength between the yellow-poplar and the southern pine veneered composites. There was no difference in tensile strength due to width. Also, there was no consistent reduction in tensile strength of MOE due to using lower-grade veneers in one of the four plies of the composite.

Keywords: Southern pine, yellow-poplar, MOE, allowable load, design load, veneer grade, COM-PLY.

July 1984
Southeastern Forest Experiment Station
200 Weaver Blvd.
Asheville, North Carolina 28804

Tensile Strength of Composite Truss Lumber as Affected by Veneer Species and Member Width

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Cooperative Research by
U.S. Department of Agriculture, Forest Service
Southeastern Forest Experiment Station
and
U.S. Department of Housing and Urban Development
Division of Energy, Building Technology
and Standards

Preface

This report is one of a series on the possibilities of producing house framing and structural panels with flakeboard cores and veneer facings. These COM-PLY or composite materials were designed to be used interchangeably with conventional lumber and plywood in housing. Research on structural framing was initially limited to COM-PLY studs but has now been extended to include larger members such as floor joists and roof truss framing.

In 1973, the home-building industry faced a shortage of lumber and plywood and consequent rising prices. Both industry and government recognized that this was not a temporary problem and that long-range plans for better using the Nation's available forest resources would be necessary.

The Forest Service of the U.S. Department of Agriculture and the U.S. Department of Housing and Urban Development accelerated cooperative research on ways to utilize the whole tree. They concentrated on composite wood products made with flakeboard and veneer as a way of using not only more of the tree stem, but also using less desirable trees and a greater variety of tree species than would be used for conventional wood products. The flakeboard, which constitutes a large portion of COM-PLY studs and joists, is made from flaked-up wood that comes from forest residues, mill residues, or low-quality timber. Thus, such composites could greatly increase the amount of lumber and plywood available for residential construction, our major use of wood, without eroding the Nation's timber supply.

Research on composite wall and floor framing was performed by the Wood Products Research Unit, Southeastern Forest Experiment Station, Athens, Ga. The American Plywood Association cooperated in these studies by designing and testing composite panel products that are interchangeable with plywood. Both types of products have been incorporated in demonstration houses.

Included in this series will be reports on structural properties, durability, dimensional stability, strength, and stiffness of composite studs and joists. Other reports will describe the overall project, compare the strength of composite and solid-wood lumber, suggest performance standards for composite lumber, and provide construction details on houses incorporating such lumber. Still others will explore the economic feasibility of manufacturing composite lumber and panels and estimate the amount and quality of veneer available from southern pines. These reports, called the COM-PLY series, will be available from the Southeastern Forest Experiment Station and U.S. Department of Housing and Urban Development.

COM-PLY® is a registered trademark of the American Plywood Association.

Light-frame wood truss manufacture consumed an estimated 2 billion board feet of dimension lumber in 1975 (Kallio and Galligan 1979). This was a normal year for housing starts. About 75 percent of this wood volume was in nominal 2 x 4 size. This is a significant segment of the market for visually stress-graded dimension lumber of Douglas-fir and southern pine. There are definite problems for the truss fabricating industry in obtaining dependable supplies of dry, uniform quality, stress-graded dimension lumber. The trend is towards the use of machine stress-rated (MSR) lumber that has less variability than the visually stress-graded lumber presently available.

Preliminary tests of composite truss lumber have shown that working stresses, stiffness, and connector strength values were in the range required for efficient truss design and generally higher than for No. 2 kiln-dried southern pine dimension lumber.

This report on the tensile characteristics of composite truss lumber is one of a series on the engineering properties of COM-PLY truss lumber and the development of performance criteria for this product.

Composite truss lumber can be designed and manufactured to meet performance requirements for use in light-frame wood trusses. This could help in solving the problems of warped, poorly dried, and miscut lumber for the truss fabrication industry.

Objectives

The objectives of this study were to determine the effect of veneer species, veneer grade, and lumber width on the tensile MOE and the allowable tensile working stress of composite truss lumber. The specific objectives of the study were to determine

- tensile MOE and tensile strength of composite truss lumber made with southern pine and yellow-poplar veneer
- allowable tensile working stress (F_t) of composite truss lumber made with southern pine and yellow-poplar veneer
- allowable tensile working stress (F_t) of composite truss lumber made with southern pine and yellow-poplar veneer where one of the four plies of the composite is of D grade veneer
- effect of lumber width on the allowable tensile working stress (F_t) of nominal 2-inch-thick composite truss lumber made with three plies of C grade veneer and one ply of D grade veneer of southern pine.

Materials and Testing

Veneer

Southern pine and yellow-poplar veneer with a nominal thickness of 1/6 inch (0.167 inch) was used as the veneer component. All veneer was obtained from regular production runs in commercial softwood plywood mills. All veneer was graded to the specifications in Commerical Standards for Softwood Plywood PS1-74 (American Plywood Association 1974). The veneer was dried to less than 6 percent moisture content at a temperature of 350° F, in a steam-heated, jet-type veneer dryer.

Core

A mechanically oriented flakeboard was used as the core material for the composite truss lumber. The material was manufactured to the following specifications:

Thickness:	7/16 inch, sanded
Panel size:	50 x 100 inches, trimmed
Orientation:	flake particles mechanically oriented parallel to long axis of panel
Furnish:	southern pine flakes, average length 1-7/8 inches and average thickness 0.030 inch
Density:	40 lb/ft^3
Binder:	6 percent phenolic resin (solids basis) with 1 percent wax (solids basis) added

Two thicknesses of the 7/16-inch flakeboard were laminated together to form the required 7/8-inch-thick core for the composite truss lumber.

Adhesive

All gluelines were made with a phenol-resorcinol adhesive. The adhesive was spread at the rate of 50 to 60 pounds per thousand square feet of glueline between veneer layers and at 80 to 90 pounds per thousand square feet of glueline for the veneer-to-core bondline. Closed assembly time was 20 minutes. The adhesive was cured under a pressure of 125 to 150 psi at 70° F for a minimum of 20 hours. The adhesive bonds were allowed to cure for an additional 24 hours at 70° F before further manufacturing operations.

Procedures

Experimental Design

The study objectives were divided into two phases of testing. Phase 1 variables were southern pine versus yellow-poplar veneers and four plies of C grade or better veneer versus three plies of C grade or better veneer and one ply of D grade veneer (the D grade veneer was always located in an interior ply). We assumed that differences between the study groups might be slight. For this reason we used 20 replicates of each variable. The experimental design for Phase 1 was a 2 x 2 factorial with 20 replications.

Phase 2 of the study examined the effect of member width on the tensile strength of composite truss lumber made up of three plies of C grade or better and one ply of D grade southern pine veneer. In this phase the only variable studied was member width. Ten samples each of 4-, 6-, 8-, and 10-inch nominal widths were tested in tension.

Fabrication

We felt that the length of the member tested in tension might have some effect on the results of the tensile strength and tensile MOE tests. Therefore, all of the specimens were made 14 feet long. The plies were laid up as shown in figure 1. Thus the length of the specimen and the location of veneer and core joints within the specimen were eliminated as variables. All samples were made in blanks 1-1/2 x 12 inches x 14 feet long. These blanks were then ripped to the proper width before testing.

Testing

The tension tests of the composite truss lumber were conducted at the Forest Products Laboratory (FPL) on the FPL Tension Tester (fig. 2). The tests were performed following the principles of ASTM D 198-78, ¶32 to ¶36 (1982b). The test span was 108 inches. The gage length for MOE determinations was 72 inches. Consultation with researchers experienced in tension tests of dimension lumber indicated that there is some relationship between test results and test span if the span between the grips is less than 10 times the width of the sample. The length of all samples was held constant to eliminate this variable and so that the joint location and pattern would be the same for all samples. There were no problems with slippage in the grips or with tension failures in the grip area.

All samples were weighed and measured immediately prior to test. Weights were recorded to the nearest 0.1 pound. Width and thickness at midspan were recorded to the nearest 0.001 inch.

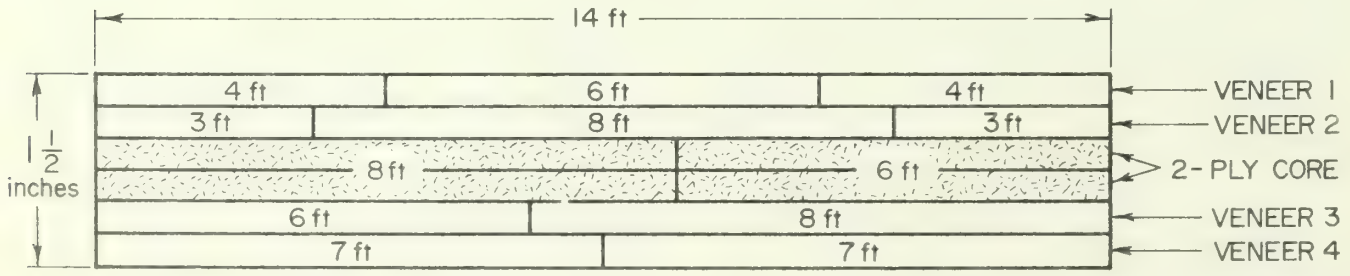
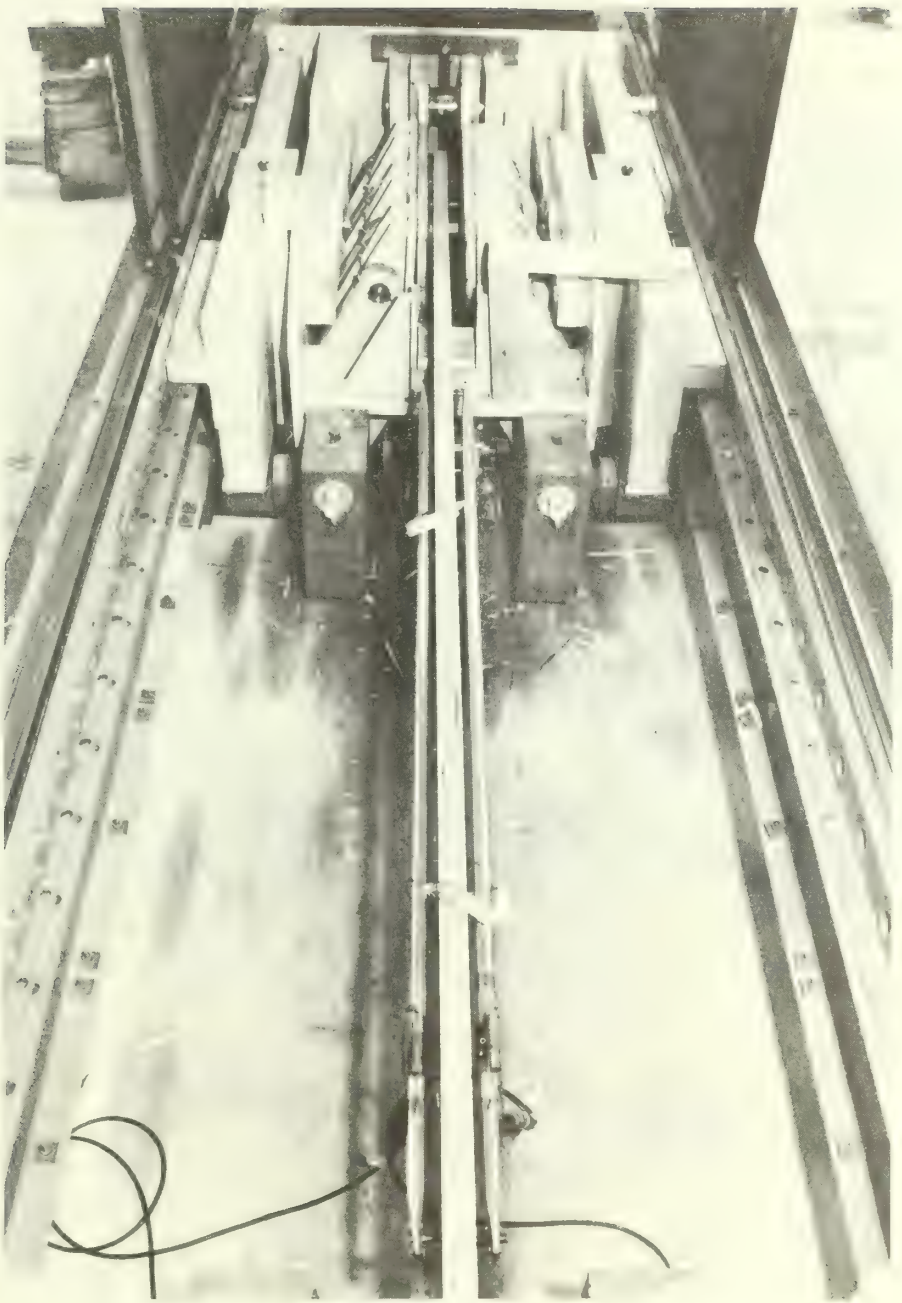


Figure 1.-- Schematic of blank layup for COM-PLY truss lumber.



FPL M 830 230-6

Figure 2.--Tension test of composite truss lumber on the FPL Tension Tester.

Moisture content was determined for every fifth test specimen. Specimens were tested in random order.

We had intended to test every member for MOE. The variation in MOE between samples was so slight that we limited the MOE determinations to 10 southern pine 2 x 4's, 10 yellow-poplar 2 x 4's, and 3 each of the 2 x 6's, 2 x 8's, and 2 x 10's for each species.

Calculations of Allowable Design Load

The allowable design stress in tension F_t was calculated by the methods outlined in ASTM D 245-81 (1982a). The formula is:

$$F_t = \frac{\text{Avg. tensile strength} - t_{0.05}\ \text{SD}}{2.1}$$

where

$t_{0.05}$ = 1.729 for 19 degrees of freedom

$t_{0.05}$ = 1.833 for 9 degrees of freedom

SD = standard deviation of tensile strength

Results and Discussion

A major objective of this study was to determine the tensile MOE of composite truss lumber made with southern pine and yellow-poplar veneers. Results of the MOE determinations are summarized in table 1. Note that there is no difference in average tensile MOE for composites made with the two species. The standard deviation of the MOE for the yellow-poplar truss lumber was about half that for southern pine truss lumber.

The typical failure pattern in tension was associated with a butt-joint in one of the outer veneer plies. Initial failure of the butt-joint was followed by a clean tension break across the other veneer layers and the core (fig. 3). Most of the failures were not associated with a butt-joint in the core layer. Summary data for Phase 1 are shown in table 2. Note that there is no statistically significant difference in tensile strength between the composites made of southern pine and yellow-poplar veneers of C grade or better quality. The coefficient of variation (CV) of the tensile strength of the two groups is fairly high at over 17 percent. Veneer of the two species could be used interchangeably in the manufacture of composite truss lumber.

The relationship between the species when one ply of D grade veneer is substituted for one of the C grade plies is not so clear-cut. For southern pine, substituting one ply of D grade veneer significantly lowered the tensile strength of the composite. Substituting one ply of yellow-poplar grade D veneer increased the tensile strength (but not a statistically significant amount). Either there is some major difference between the southern pine and yellow-poplar D grade veneers or there was a 1-in-20 sampling error for the yellow-poplar.

Table 1.--Tensile modulus of elasticity of composite truss lumber 2 x 4's made with two species of veneer

Species	Number of samples	Tensile MOE		Coefficient of variation
		Average	SD	
		- - - psi x 10^6 - - -		%
Southern pine	10	1.30	0.12	9.2
Yellow-poplar	10	1.30	0.06	4.6

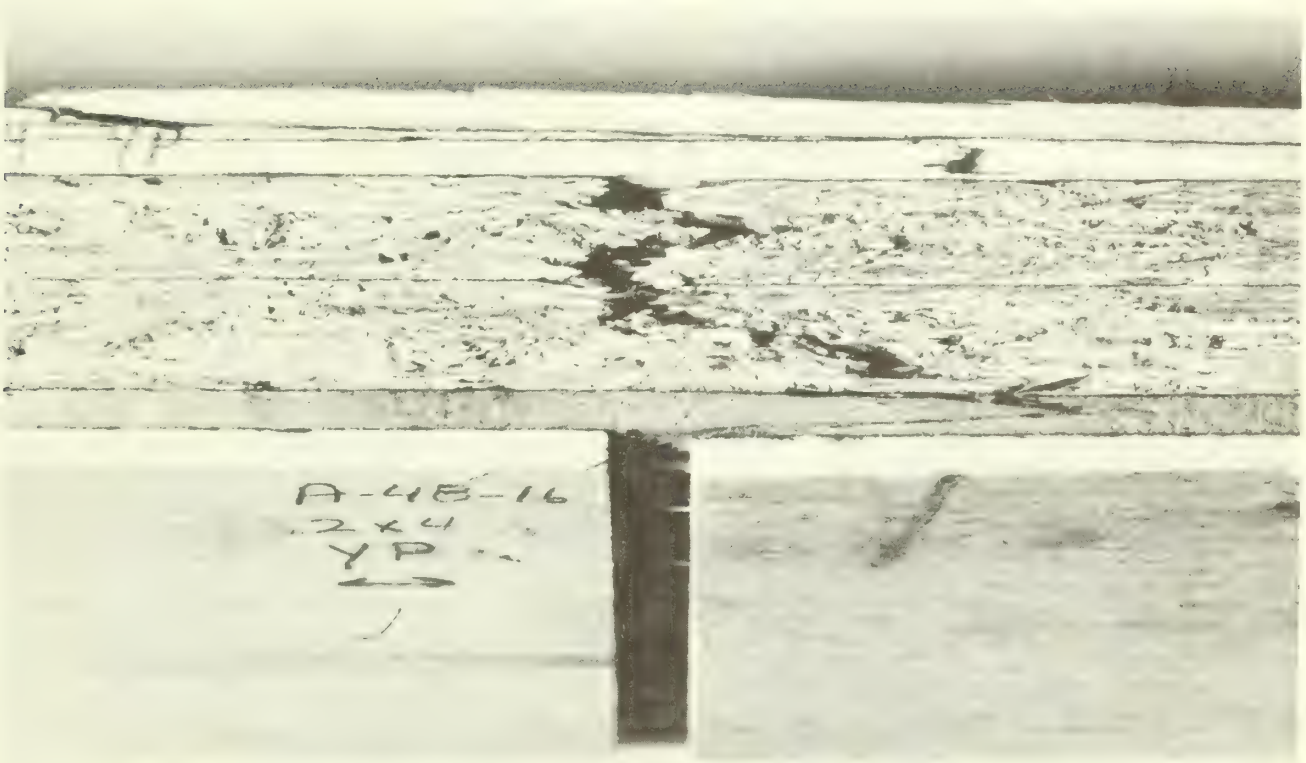


Figure 3.--Typical tension failure pattern of composite truss lumber.

Table 2.--Tensile strength of composite truss lumber 2 x 4's as affected by veneer species and veneer grade

Veneer grade	Number of samples	Tensile Strength		Coefficient of variation	F_t allowable design stress
		Average	SD		
		psi		%	*psi*
SOUTHERN PINE					
All C or better	20	2,538[a]	433	17.1	852
1/4 D	20	1,885[b]	342	18.1	616
YELLOW-POPLAR					
All C or better	20	2,439[a]	520	21.3	733
1/4 D	20	2,832[a]	356	12.6	1,050

Values followed by the same letter are not significantly different at the 95 percent level as determined by Duncan's multiple range test.

Summary data for Phase 2 of the study are presented in table 3. Note that there is very little difference in either MOE or tensile strength of the different widths of composite truss lumber. The allowable design load in tension, F_t, is also essentially the same for all widths tested. This lack of difference in tensile strength due to width of the member was expected since the four veneer plies tend to randomize the defect pattern.

Table 3.--Effect of member size on the tensile strength and allowable design load in tension of composite truss lumber made with southern pine veneers

Member size	Number of samples	MOE	Tensile strength		Coefficient of variation	F_t allowable design stress
			Average	SD		
		psi x 10^6	*psi*		%	*psi*
2 x 4	10	1.30	2,011[a]	317	15.8	681
2 x 6	10	1.27	2,174[a]	484	22.3	613
2 x 8	10	1.28	2,137[a]	397	18.6	671
2 x 10	10	1.27	2,059[a]	282	13.7	734

Values followed by the same letter are not significantly different at the 95 percent level as determined by Duncan's multiple range test.

The F_t values were somewhat lower than we had expected based on the tensile strength of the components tested separately. Tension failure pattern of the specimens seemed to indicate that either the strength or tensile elongation of the core material may have limited the ultimate tensile strength of the composite. We have planned additional tensile strength studies using a more highly oriented core material with greater tensile strength than the core material used in this study.

It should be noted that the F_t value for this composite truss lumber is in keeping with the F_t for MSR lumber with a MOE of 1.3 million psi (WWPA 1978; SPIB 1977). However, this is not a commonly used or specified grade of material used in the design and fabrication of trusses.

Conclusions

The following conclusions may be drawn based on the results of this study:

- There is no difference in MOE between composite truss lumber 2 x 4's made with southern pine or yellow-poplar veneers.
- There is no significant difference in the tensile strength of composite truss lumber 2 x 4's made with southern pine or yellow-poplar veneers if all of the veneers are of C grade or better quality.
- There is no significant difference in the tensile strength of composite truss lumber due to width. In other words, 2 x 10's are just as strong as 2 x 4's on a load per unit area basis.

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McAlister, Robert H.

Tensile strength of composite truss lumber as affected by veneer species and member width. Res. Pap. SE-246. COM-PLY Rep. 27. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1984. 9 p.

One hundred and twenty pieces of composite truss lumber made with southern pine and yellow-poplar veneers of varying grades and in nominal widths from 2 x 4 to 2 x 10 were tested in tension. The modulus of elasticity (MOE) for both species was about 1.3 million psi. There were no differences in tensile strength between the yellow-poplar and the southern pine veneered composities. There was no difference in tensile strength due to width. Also, there was no consistent reduction in tensile strength of MOE due to using lower-grade veneers in one of the four plies of the composite.

KEYWORDS: Southern pine, yellow-poplar, MOE, allowable load, design load, veneer grade, COM-PLY.

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Other COM-PLY Reports

Res. Pap.	Title and Author
SE-166	The COM-PLY Research Project. Koenigshof 1977 (Rep. 1)
SE-155	Performance Standards for Composite Studs Used in Exterior Walls. Blomquist and others 1976 (Rep. 2)
SE-163	Plywood Composite Panels for Floors and Roofs: Summary Report. Carney 1977 (Rep. 3)
SE-167	Laminating COM-PLY Studs in a Factory Vick 1977 (Rep. 4)
SE-170	Strength and Stiffness of Composite Studs. Wittenberg 1977 (Rep. 5)
SE-171	Adhesives for COM-PLY Studs. Vick 1977 (Rep. 6)
SE-172	Durability and Dimensional Stability of COM-PLY Studs. Duff 1977 (Rep. 7)
SE-175	Structural Performance of Nailed Joints With COM-PLY. Walker 1977 (Rep. 8)
SE-179	Yield of Southern Pine Veneer Suitable for Composite Lumber and Panels. McAlister and Taras 1978 (Rep. 9)
SE-177	Demonstration Houses Built With COM-PLY Products. Koenigshof and others 1977 (Rep. 10)
SE-178	Comparative Racking Strength of Walls Framed With COM-PLY and Sawn Timber Studs. Wittenberg 1978 (Rep. 11)
SE-180	Structural Properties of COM-PLY Studs. McAlister 1978 (Rep. 12)
SE-181	Structural Performance and Standards for COM-PLY Partition Studs. Koenigshof and Wittenberg 1978 (Rep. 13)
SE-192	Performance Standards for COM-PLY Floor Joists. Duff and Wittenberg 1978 (Rep. 14)
SE-197	Economic Feasibility of Manufacturing COM-PLY Studs in the South. Koenigshof 1978 (Rep. 15)
SE-199	Structural Performance of COM-PLY Studs Made With Hardwood Veneers. McAlister 1979 (Rep. 16)
SE-201	Economic Feasibility of Manufacturing COM-PLY Panels in the South. Koenigshof 1979 (Rep. 17)
SE-207	Dimensional Stability and Durability of COM-PLY Studs Exposed to Soaking, High Humidity, and Weathering. Duff 1980 (Rep. 18)
SE-220	Evaluation of Veneer Yields and Grades From Yellow-Poplar, White Oak, and Sweetgum From the Southeast. McAlister 1981 (Rep. 19)
SE-222	End Bearing and Joint Strength of COM-PLY Joists. Wittenberg 1981 (Rep. 20)
SE-224	Linear Expansion Design Theory for COM-PLY® Panels. Talbott and others 1981 (Rep. 21)
SE-225	Resistance of COM-PLY Lumber to Subterranean Termites. Gaby and Carter 1981 (Rep. 22)
Unnumbered (In-House)	Modulus of Elasticity and Tensile Strength Distribution of Veneer of Four Commercially Important Southestern Hardwoods. McAlister 1982 (Rep. 23)
SE-238	Veneer Yields by Grade From Three Coastal Plain Hardwoods--Blackgum, Sweetgum, and Yellow-Poplar. McAlister and Clark 1983 (Rep. 24)
SE-239	Effect of Veneer Grade on Bending and Compression of COM-PLY Truss Lumber. McAlister 1983 (Rep. 25)
SE-241	Economic Feasibility of Manufacturing COM-PLY Floor Joists. Koenigshof 1983 (Rep. 26)

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Research Paper
SE-247

Multiresource Inventories: Watershed Condition of Commercial Forest Land in South Carolina

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July 1984

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Multiresource Inventories: Watershed Condition of Commercial Forest Land in South Carolina

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ABSTRACT

Multiresource inventory data collected on commercial forest land in South Carolina were used to evaluate the relative state of watershed conditions on a statewide basis. The data collected and techniques for analyzing the data are described. Watershed conditions are relatively good, with some apparent problems associated with grazing, site preparation, and roads. The management of a large volume of timber may be affected by environmental laws related to water.

Keywords: Watershed management, soils, hydrology, timber management.

In the Southeast, acceleration and intensification of silvicultural practices are normally done on areas that promise the greatest return in terms of timber. If intensive management or silviculture is practiced on areas where forest soils are unstable, both soil and water resources can be impaired. To protect both resources, periodic statewide inventories of information on soil, vegetation, erosion, and runoff problems are essential.

This paper describes how multiresource data gathered in South Carolina can be used to evaluate trade-offs between timber production and protection of soil and water resources and to develop general information about the resources, which can be used for regional, State, and county planning.

Soil and Water Data

Data used to evaluate watershed conditions were collected by USDA Forest Service, Forest Inventory and Analysis (FIA) field crews throughout South Carolina during 1977 and 1978. Such inventories are authorized by the Forest and Rangeland Renewable Resources Research Act of 1978. More detailed information on the history and purpose of State inventories is available (McClure and others 1979).

Soil and hydrologic data were collected on 4,034 permanent sample plots established on commercial forest land throughout South Carolina. Commercial forest acreage in the State totals 12.5 million acres, representing a broad range of forest conditions (Sheffield 1979). The State contains a small portion of the Southern Appalachian Mountains, a large area of rolling piedmont laced with narrow flood plains, an extensive belt of sandhills, and a broad expanse of flat coastal plain interspersed with swamps and broad flood plains. For inventory purposes, the State is divided into three

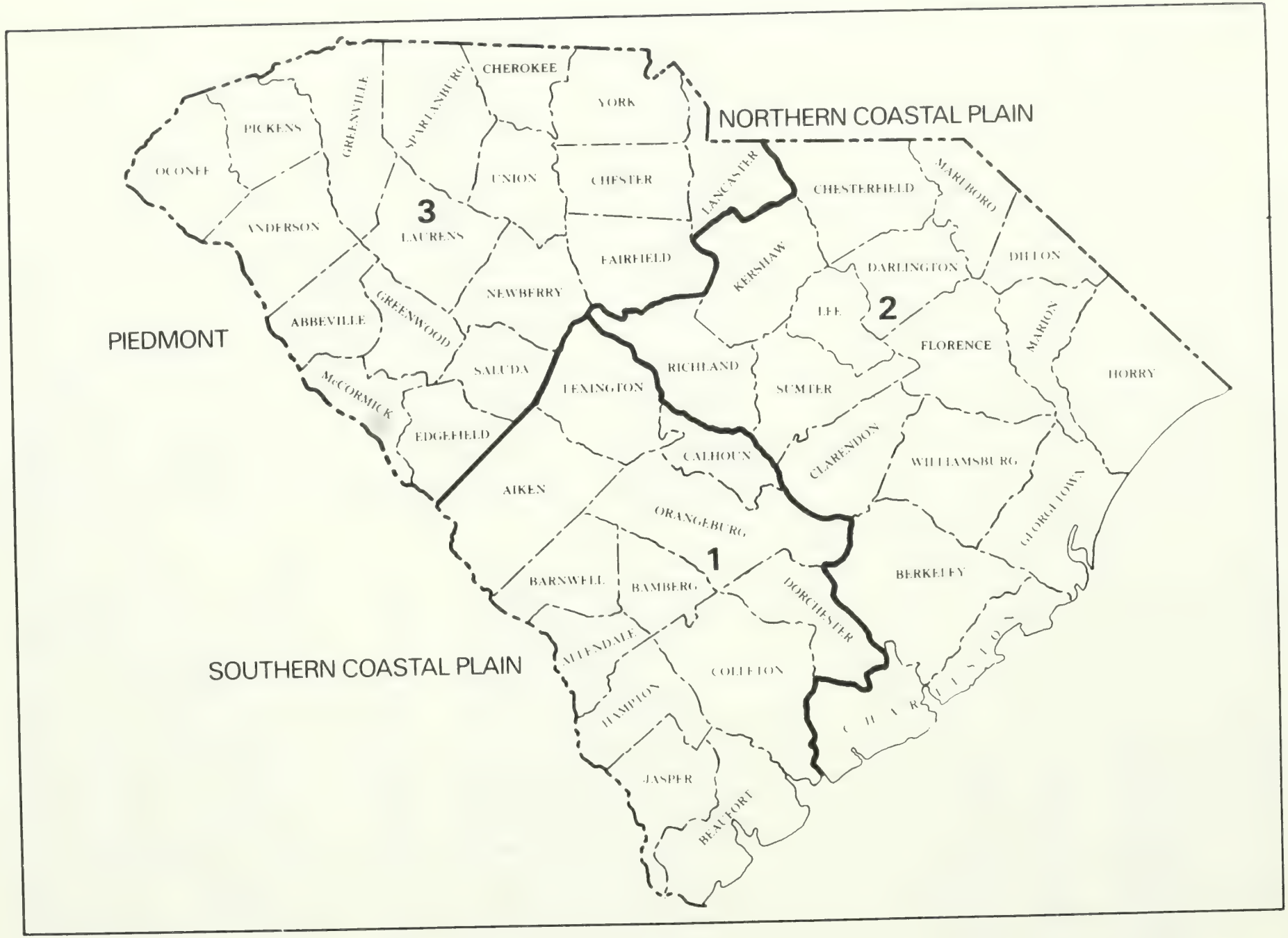


Figure 1.--Forest Survey Units in South Carolina.

Survey Units: (1) Southern Coastal Plain, (2) Northern Coastal Plain, and (3) Piedmont (fig. 1).

Previously, FIA permanent plots were used exclusively for collection of timber data. The sampling procedures for timber, however, are designed to provide reliable estimates of the area, inventory volume, growth, and removals at the Survey Unit and State levels. Little is known about the number of samples needed or degree of precision required for soil hydrologic inventories, but many of the timber-related data are useful for evaluating watershed conditions.

Watershed condition describes the state of a watershed, or portion thereof, in terms of factors which affect hydrologic function and soil productivity. For example, data on stand age, forest type, stand origin, ownership, stand history, and treatment opportunity can be used to analyze the interactions of timber, and soil and water data (Dissmeyer 1979). More specific data such as litter depth, humus depth, soil texture, percent bare soil, soil compaction, slope, slope length, and degree of soil erosion were also collected for the evaluation of watershed conditions on the three Survey Units of South Carolina.

Topsoil (A_1) Redevelopment

Foresters, soil scientists, and hydrologists are aware of the importance of the A_1 horizon (topsoil) to timber growth, soil productivity, and hydrologic characteristics of the soil. On most forest land in the Piedmont of South Carolina, the original topsoil was removed by erosion as a result of past abusive agricultural practices (Trimble 1969). How fast is A_1 redeveloping under the various timber types? Figure 2A, which shows humus depth as a function of stand age and timber type, gives some indication. Humus depth on abandoned and eroded agricultural soils corresponds to redeveloping A_1. The data suggest that A_1 redevelopment is slower under planted pine than under other timber types with larger hardwood components. The reason appears to be related to litter decomposition.

Planted pine accumulates more litter than other timber types through the first 35 to 45 years (fig. 2B). Pine litter decomposes slowly, which partially explains the slower topsoil development under pine. Silvicultural practices on abandoned farmland should be designed to protect the redeveloping topsoil and allow the process to continue. This type of management can lead to improved soil productivity.

Slope Class Distribution

Slope class distribution was produced for plots in various treatment or disturbance conditions. About 54 percent of the logging and thinning in the Piedmont (fig. 3A) and 95 percent in the Coastal Plain (fig. 3B) occurred on slopes less than 10 percent. In the Piedmont all mechanical site preparation was on slopes less than 20 percent. In the Coastal Plain 85.7 percent of the site preparation was on slopes of less than 10 percent, none on 10 to 19 percent slope, and 14.3 percent on 20 to 29 percent slope, which suggests that intensive silviculture is being concentrated on gentle slopes.

Erosion From Logging

Logging exposes soil to erosion through skidding, skid trails, and roads. FIA crews collected data on the amount of bare soil found on each plot. With FIA data, the percentage of bare soil was plotted against time (years) since logging (fig. 4). Bare soil requires about 4 years to heal. In the Piedmont, the average amount of bare soil ranged from 9 percent 1 year after disturbance to less than 2 percent for 4 years. For the entire 4-year period, the average bare ground was 5.7 percent.

The percentage of bare ground can be converted into a cover factor for use in the Universal Soil Loss Equation (USLE) to predict an erosion rate for logging. The USLE (Wischmeier and Smith 1978) is:

$$A = R \cdot K \cdot S \cdot L \cdot CP$$

where:

A = predicted soil loss (tons/acre/year)

R = rainfall energy factor (read from map)

K = basic soil erosion rate

S = slope (percent)

L = slope length (feet)

CP = cover factor

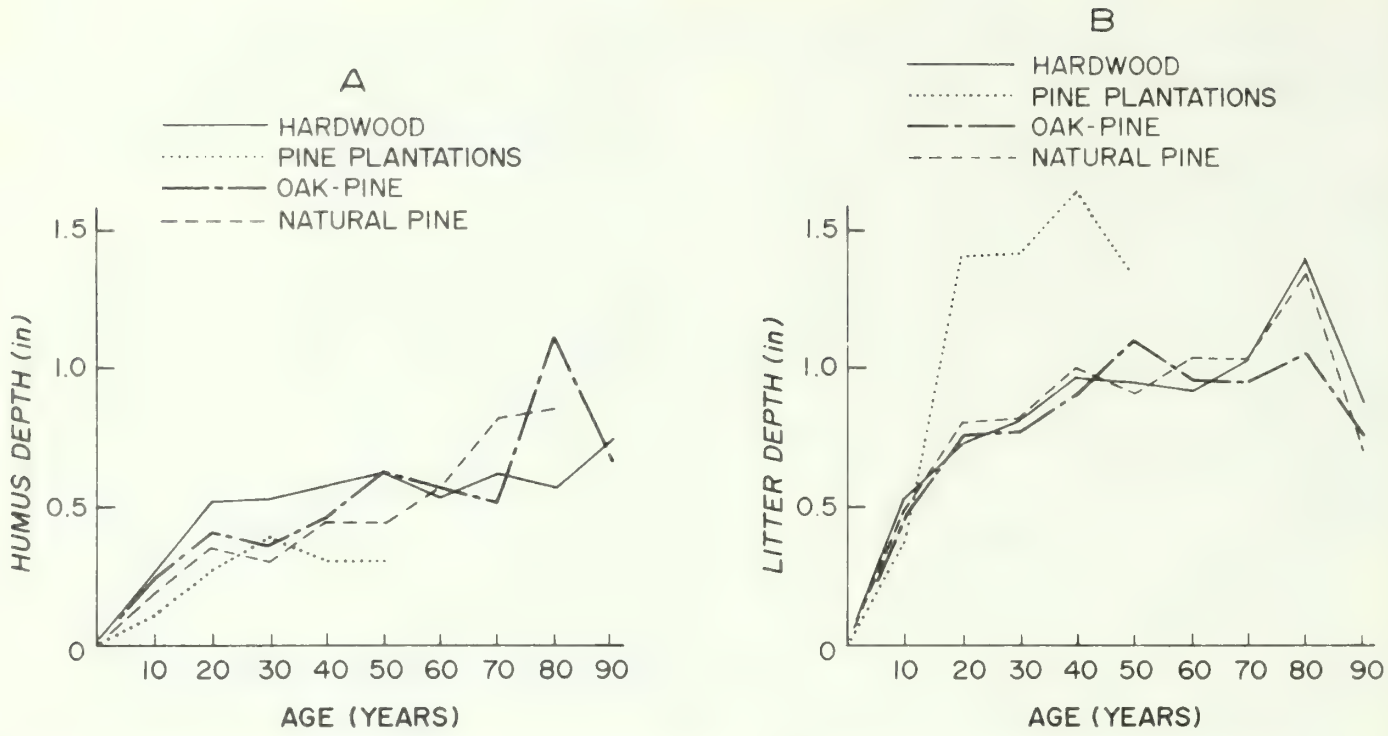


Figure 2.--Humus depth (A) and litter depth (B) as a function of stand age and timber type for the Piedmont.

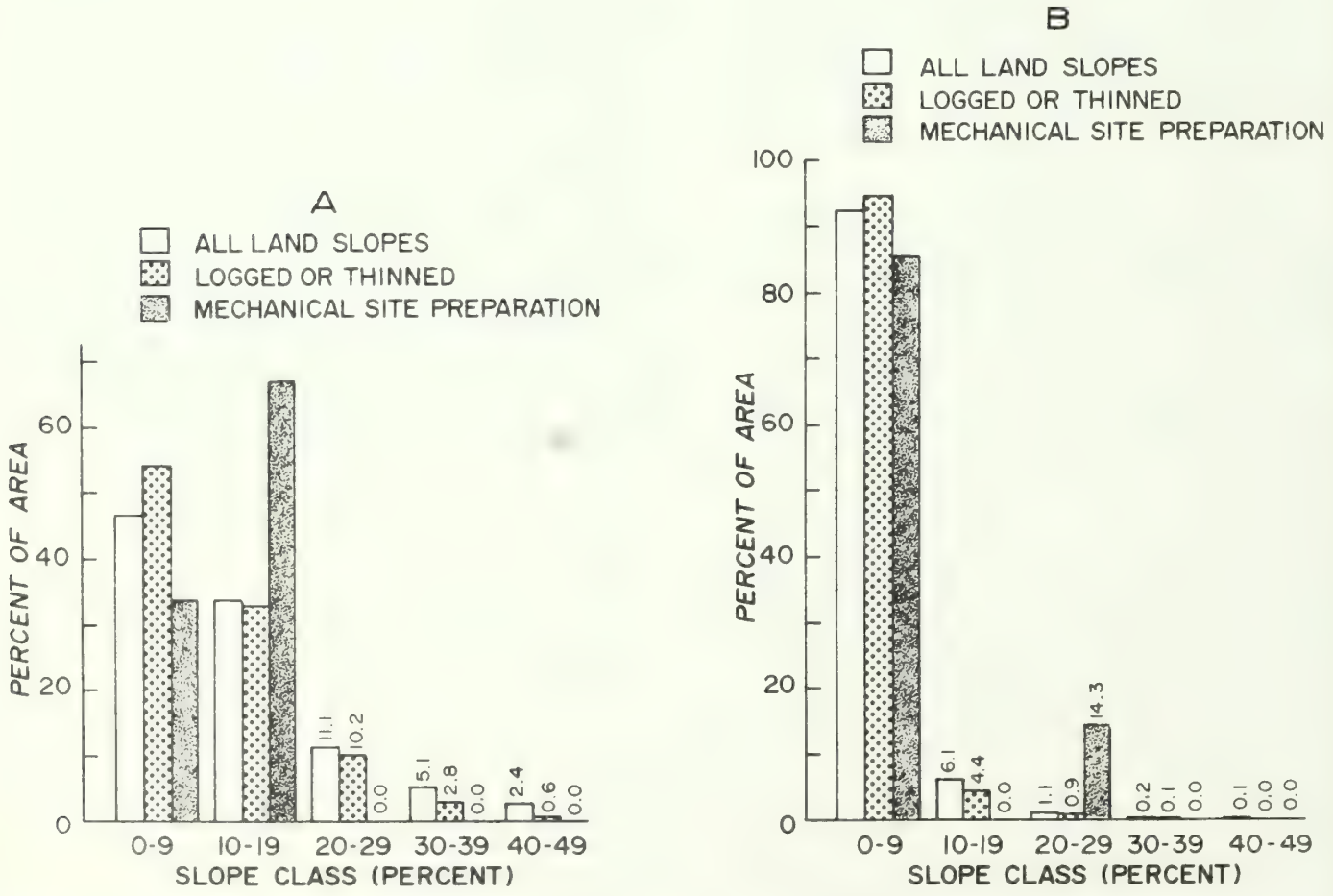


Figure 3.--Slope class distribution for all plots sampled, logged areas, and site-prepared areas in the Piedmont (A) and in the Coastal Plain (B), South Carolina.

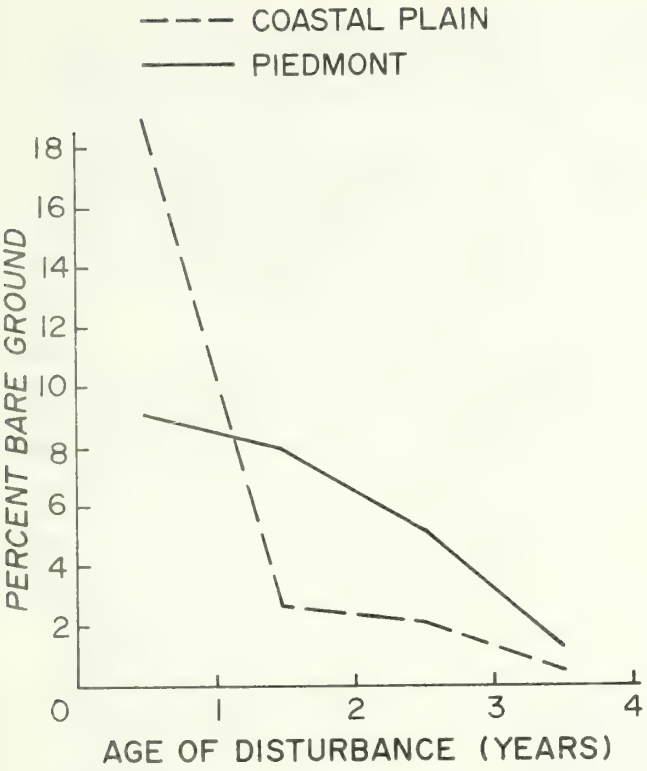


Figure 4.--Percentage of bare ground as a function of years since logging.

The cover factor, which expresses the impact of a management practice on erosion, for 5.7 percent bare ground is 0.003 (Dissmeyer and Foster 1980). The resultant erosion rate calculated using the average slope derived from the slope class distribution and average L, K, and R values for the Piedmont (Dissmeyer and Stump 1978) would be 0.4 ton per acre per year. By using FIA data, the USLE, and other sources of data, erosion rates can be predicted for various forest management practices and conditions. Thus planners can compute trade-offs between erosion and wood production under various alternatives.

FIA data indicate that accelerated erosion due to logging is occurring on approximately 290,000 acres of Piedmont forest. This area is four times the acreage cut each year in this region. The number of acres on which conditions and practices are causing accelerated erosion are needed for water quality management[1] and RPA planning.

[1]Water quality management planning by States is required by Section 208 of the Amendments to the Federal Water Pollution Control Act of 1972 (PL 92-500).

In RPA assessment of program alternatives, each alternative logging area with its subsequent erosion can be projected. For example, under present conditions, the total erosion volume from logging is 0.4 ton per acre per year times 290,000 acres or 116,000 tons per year. If an alternative increased the logging area by 50 percent, then the erosion volume would be increased to 174,000 tons per year.

Logged areas in the Coastal Plain have an average of 6 percent bare soil for the recovery period, and an average erosion rate of approximately 0.13 ton per acre per year for the recovery period. The Coastal Plain's slopes are gentler and the soils are less erosive than the Piedmont's, thus a lower erosion rate. During the past 4 years, approximately 576,000 acres were logged in the Coastal Plain, with an estimated erosion of 85,000 tons per year. Total erosion for logging in South Carolina is approximately 201,000 tons per year.

Soil and Water Quality

Risk Classification

A risk classification for soil and water quality provides a basis for interpreting potential trade-offs. The classification we have developed expresses the inherent potential of both a site and a management practice to produce soil erosion and water quality problems. The concept is that part of the risk is associated with the site and part with the type of management to be imposed on the site. A high-risk management practice on a high-risk site could lead to serious soil erosion and water quality problems. However, if a low-risk management practice is imposed on a high-risk site, the result might be a moderate potential for soil erosion and water quality impacts, which might be further reduced by preventive measures. The risk class was derived for each plot by employing the USLE. Three items of FIA data (soil texture, percent land slope, and percent bare soil, from which cover factors are derived) were used along with average R and L values from secondary sources (Dissmeyer and Stump 1978). The five FIA soil textures were assigned K factors:

Texture	*K factor*
Sand	0.14
Sandy loam	0.19
Loam	0.26
Clay loam	0.35
Clay	0.30

An erosion rate was predicted for each plot for high- and low-risk management practices by using the USLE.

The risk classes assigned to site management conditions are determined by predicting the average erosion rate for the recovery period of the disturbance:

Risk class	*Erosion rate (tons/acre/year)*
1	0.00 to 0.25
2	0.26 to 3.1
3	3.11 to 5.1
4	5.11 to 22.0
5	22.01+

The risk classes can also be described in terms of soil loss and general effects on water quality. Soil scientists have assigned tolerable losses for soils based on expected rates of new soil formation. The tolerable values range from 1 to 5 tons per acre per year for Piedmont soils in South Carolina (USDA SCS 1976). In these terms, the definitions of the risk classes are:

Risk class	*Definition*
1	During the recovery period of the activity, the water quality impact should be slight and soil erosion less than the rate of new soil development
2	Water quality during the recovery period of the activity could be impaired, and soil erosion should not exceed the rate of new soil development
3	Water quality impacts could be high and soil erosion could exceed the rate of new soil development during the recovery period
4	Water quality impacts could be serious, and soil erosion could exceed the rate of new soil development for 5 to 20 years after treatment
5	Water quality impacts could be very serious, and soil erosion could exceed the rate of new soil development for more than 20 years after treatment

As the risk classification increases, so does the potential for water quality degradation and the threat of soil productivity losses.

As an example, a classification table was developed for high- and low-risk management activities (table 1). The high-risk activities are mechanical site preparation with disking or shearing and windrowing. The low-risk activities are logging and injecting unwanted trees with herbicides, or preparing sites by chopping unwanted vegetation. It is clear that threat to soil and water quality can be greatly reduced by using low-risk silvicultural practices. For example, a high-risk practice on a clay loam soil and a 20 percent slope can be reduced from a 4 to a 2 rating by using a low-risk practice.

Site Productivity vs. Risk Class

Intensive silviculture often employs high-risk site preparation practices such as shearing and windrowing, and disking, which are expensive. To get a satisfactory return on investment requires that expensive practices be used on the better sites. The question becomes, how does site productivity correspond to risk class? FIA classified productivity into five site classes:

Site class	*Potential yield, mean annual increment*
1	More than 165 ft^3/acre/year
2	120 to 165 ft^3/acre/year
3	85 to 120 ft^3/acre/year
4	50 to 85 ft^3/acre/year
5	Less than 50 but more than 20 ft^3/acre/year

The best commercial forest land is represented by site classes 1, 2, and 3 which were grouped together for this analysis. Classes 4 and 5 were analyzed separately.

Table 1.--Risk classification table for soil and water quality for high-and low-risk management, by slope and soil texture

Slope (%)	Sand		Sandy loam		Loam		Clay loam		Clay	
	H	L	H	L	H	L	H	L	H	L
1	1	1	1	1	2	1	2	1	2	1
2	2	1	2	1	2	1	2	1	2	1
4	2	1	2	1	2	1	2	1	2	1
6	2	1	2	1	2	1	2	1	2	1
8	2	1	2	1	2	1	2	2	2	2
10	2	1	2	1	3	2	3	2	3	2
15	3	2	3	2	3	2	4	2	3	2
20	3	2	4	2	4	2	4	2	4	2
25	4	2	4	2	4	2	4	2	4	2
30	4	2	4	2	4	2	4	2	4	2
40	4	2	4	2	5	2	5	3	5	3
50	4	2	5	2	5	3	5	4	5	3

H = high risk; L = low risk.

Site class was plotted against risk class for the Piedmont (fig. 5). This figure shows a tendency for land of low productivity to be classified as high-risk areas. Investments in intensive forest management may not be justified on such lands. The return on investment may be too low, and the risks of soil and water damage are too high.

The area logged appears to closely follow the distribution of site classes 1, 2, and 3 in the Piedmont. Better timber and more favorable economics are associated with these sites. Only 0.8 percent of the present logging in the Piedmont was found on risk class 3 lands (fig. 5B), which suggests that today's logging does not create much of a soil or water quality impact. This is useful information for water quality planners and State Foresters.

The most productive sites (1, 2, and 3) are probably those where most intensive silvicultural practices, like mechanical site preparation for tree planting, will be applied. If risk classes 3 and above are judged unacceptable, then 24.4 percent of Piedmont land in site classes 1, 2, and 3 should not be sheared and windrowed (fig. 5A). Nearly all of this land could be prepared for tree planting by low-risk management (fig. 5B). More than 99 percent of the land in the Coastal Plain falls in risk classes 1 and 2, even under high-risk management (see table 3).

Treatment Opportunities

FIA data revealed that approximately 4,868,216 acres of commercial forest land will need some type of silvicultural treatment during the next 10 years. This is 39 percent of the forest in the study area. These practices could increase timber supply, but at what cost to soil and water quality? Tables 2 and 3 summarize treatment opportunities by soil and water quality risk class for both high- and low-risk silvicultural practices.

It is apparent that the silvicultural practices used to exploit treatment opportunities will significantly influence soil and water quality. For example, timber production on 507,406 acres in the Piedmont could be increased through stand conversion and artificial regeneration with site preparation. If shearing and windrowing is used, 149,189 acres of land would fall in class 1 (slight impact on water quality and soil). However, if chopping or injection is used, the area in risk class 1 increases by 179,392 acres to a total 328,581 acres, or 65 percent of the area needing treatment rather than 29 percent. If risk classes 3 and above were judged as unacceptable, then shearing and windrowing would be unacceptable on 178,825 acres. Conversely, chopping or herbicide injection would be unacceptable on only 13,997 acres.

In the Coastal Plain, site preparation by shearing and windrowing would be unacceptable on only 7,437 acres, and a less hazardous treatment would allow these acres to be treated with acceptable risk to soil and water quality. Again, this analysis shows the relatively low risk associated with forest management in the Coastal Plain.

As for harvesting opportunities in the Piedmont, 36,331 acres should not be cut by using logging systems prevalent in the area. On these acres, improved harvesting systems, for example cable systems, with lower risks should be considered.

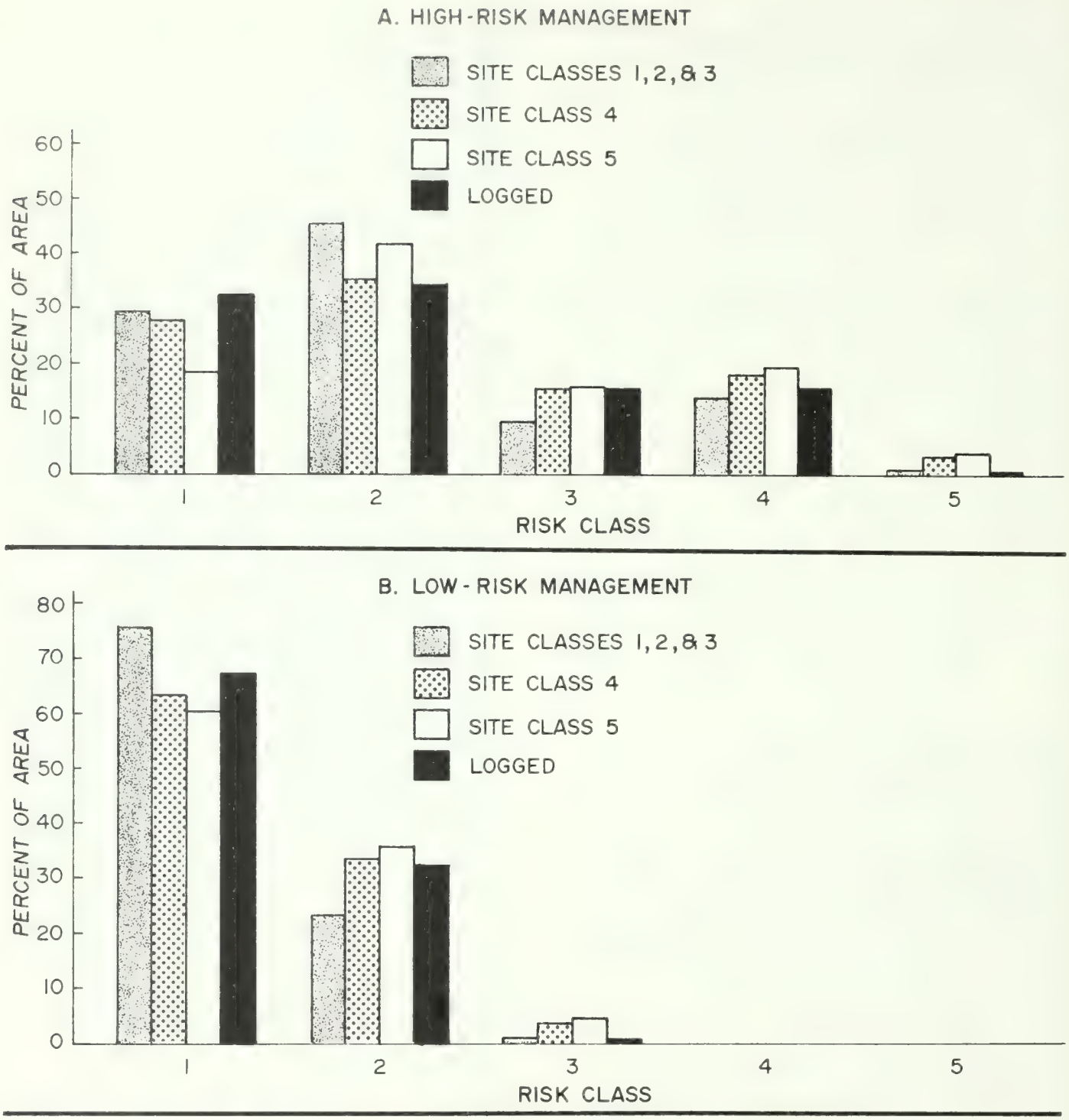


Figure 5.--Site productivity and logged area distribution as a function of risk class for soil and water quality, Piedmont, South Carolina.

Table 2.--Area of commerical forest land in the Piedmont of South Carolina, by treatment opportunity and soil and water quality risk class

Treatment opportunity	Total	Risk class asssociated with shearing and windrowing or disking				
		1	2	3	4	5
		Acres				
No treatment	3,223,011	805,939	1,267,590	500,930	569,822	78,730
Salvage cut	39,304	15,920	7,916	15,468	--	--
Harvest	209,064	42,438	66,426	14,962	48,907	36,331
Commercial thinning	212,896	110,092	85,966	9,326	7,512	--
Precommercial thinning	32,590	13,83	9,255	4,226	5,256	--
Cleaning and release	285,150	72,038	117,043	44,388	48,342	3,339
Stand conversion	155,948	35,811	70,405	21,455	23,906	4,371
Artificial regeneration w/o site preparation	18,615	11,995	5,323	--	1,297	--
Artificial regeneration w/site preparation	351,458	113,378	108,987	34,799	84,668	9,326
Total	4,528,036	1,221,464	1,738,911	645,554	789,710	132,397

	1	1	2	2	3
	Risk class associated with logging, single chop, or herbicide injection				

Forest Land Treated or Disturbed

From FIA data, the area treated or disturbed during the past remeasurement period can be computed (table 4). Data are reported by categories that provide valuable information on what practices are being used in each broad timber type by various ownerships. Practices were grouped as follows:

Harvesting With Artificial Regeneration
- Harvest followed by artificial regeneration

Harvesting With Natural Regeneration
- Harvest followed by natural regeneration (does not include seed-tree method)
- Harvest leaving seed trees, with satisfactory regeneration

Other Harvesting
- Harvest without regeneration (does not include seed-tree method)
- Removal of selected trees resulting in high grading
- Harvest leaving seed trees, without satisfactory regeneration
- Salvage cut

Intermediate Cutting
- Commercial thinning
- Precommercial thinning
- Cleaning, release, or other intermediate cutting
- Girdling or poisoning of undesirable trees

Artificial Regeneration
- After site preparation
- Without site preparation
- On nonforest land

Natural Disturbance With Significant Damage
- From wildfire
- From disease
- From insects
- From weather or other natural destructive agents

Other
- Clearing or other site preparation
- Prescribed burning
- Major drainage efforts
- Major man-caused flooding
- Grazing or other activity that retards or precludes development of understory

Table 3.--Area of commercial forest land in the Coastal Plain of South Carolina, by treatment opportunity and soil and water risk class

Treatment opportunity	Total	Risk class asssociated with shearing and windrowing or disking				
		1	2	3	4	5
		Acres				
No treatment	4,411,679	1,963,290	2,438,424	9,965	--	--
Salvage cut	76,567	37,074	39,493	--	--	--
Harvest	532,430	233,173	299,257	--	--	--
Commercial thinning	273,526	59,472	150,353	63,701	--	--
Precommercial thinning	39,868	34,702	5,166	--	--	--
Cleaning and release	526,679	244,949	278,500	3,230	--	--
Stand conversion	352,953	186,014	166,939	--	--	--
Artificial regeneration w/o site preparation	53,967	26,189	27,778	--	--	--
Artificial regeneration w/site preparation	1,707,201	698,065	1,001,699	7,437	--	--
Total	7,974,870	3,482,928	4,407,609	84,333	--	--

	1	1	2	2	3
	Risk class associated with logging, single chop, or herbicide injection				

- Turpentining
- Construction of fences, wood roads, firebreaks, trash pits, etc., if other (specified)

None
- Natural regeneration on nonforest land
- No treatment or disturbance

Pine plantations and natural pine had the most intensive management (table 4). During this remeasurement period, 374,460 acres were harvested and regenerated artificially to pine plantations. Many of the 113,480 acres established artificially were harvested just prior to the past measurement but were regenerated during this remeasurement period. Forest industry performed most of this work. During this period, shearing and windrowing--at high risk to soil and water quality--was a common practice on all ownerships. Many of these acres will need to be treated this way if proper management through the rotation does not prevent the formation of a large hardwood component. Chopping and other low-risk practices can be employed after harvest if hardwoods are controlled in present pine plantations; then future erosion rates for site preparation should be lower than in the past.

Some pine plantations were harvested but not regenerated (12,250 acres under "other harvesting"); however, less than 1 percent falls in this category. Possibly a portion of the plantations were harvested recently and are awaiting site preparation and planting. Most of this acreage is in private ownership (10,790 acres), and site preparation is often done with the bulldozer, resulting in soil and water quality risks. Some land could be prepared by chopping and burning, which would lower the impact on soil and water and save the private landowner money.

Natural pine stands dominate the pine type in South Carolina with 4,209,403 acres, compared with 1,361,517 acres of plantations. Harvesting with natural regeneration was successful on 221,276 acres (table 4), and other harvesting followed by inadequate regeneration occurred on 176,427 acres.

The 176,427 acres represent a tremendous area where additional work is needed to gain

Table 4.--Area of commercial forest land treated or disturbed between 1968-1978 in South Carolina, by timber type and ownership class

Timber type and ownership class	Total area	Harvesting with artificial regeneration	Harvesting with natural regeneration	Other harvesting	Intermediate cutting	Artificial regeneration	Natural disturbance	Other	None
	Acres								
Pine plantations									
Public	147,543	37,911	--	1,460	39,710	--	10,065	8,053	50,344
Forest industry	628,570	262,113	--	--	34,721	69,051	98,265	52,115	112,305
Other private	585,404	74,436	--	10,790	167,235	44,429	98,432	46,674	143,408
Total	1,361,517	374,460	--	12,250	241,666	113,480	206,762	106,842	306,057
Natural pine									
Public	508,735	--	22,666	11,508	184,713	--	46,297	57,850	185,701
Forest industry	600,681	--	30,651	44,860	103,742	--	75,005	74,738	271,685
Other private	3,099,987	--	167,959	120,059	555,217	--	286,942	399,617	1,570,193
Total	4,209,403	--	221,276	176,427	843,672	--	408,244	532,205	2,027,579
Oak-pine									
Public	129,053	3,338	13,088	4,473	10,957	--	18,300	19,905	58,992
Forest industry	223,439	31,474	20,703	9,691	15,475	13,145	13,603	6,283	113,065
Other private	1,366,052	8,773	107,074	84,026	243,618	--	85,275	136,252	701,034
Total	1,718,544	43,585	140,865	98,190	270,050	13,145	117,178	162,440	873,091
Upland hardwood									
Public	173,222	--	4,004	10,184	29,723	--	11,889	4,108	113,314
Forest industry	372,231	4,920	108,569	67,031	35,713	2,692	6,265	19,718	127,323
Other private	2,399,801	4,599	201,526	253,745	327,042	4,660	108,721	241,068	1,258,440
Total	2,945,254	9,519	314,099	330,960	392,478	7,352	126,875	264,894	1,499,077
Lowland hardwood									
Public	132,274	--	2,482	--	2,482	--	3,010	17,915	106,385
Forest industry	500,175	3,605	40,800	28,450	27,978	2,816	10,478	9,651	376,397
Other private	1,635,739	--	71,805	177,389	142,154	--	71,713	75,832	1,096,846
Total	2,268,188	3,605	115,087	205,839	172,614	2,816	85,201	103,398	1,579,628
All types									
Public	1,090,827	41,249	42,240	27,625	267,585	--	89,561	107,831	514,736
Forest industry	2,325,096	302,112	200,723	150,032	217,629	87,704	203,616	162,505	1,000,775
Other private	9,086,983	87,808	548,364	646,009	1,435,266	49,089	651,083	899,443	4,769,921
Total	12,502,906	431,169	791,327	823,666	1,920,480	136,793	944,260	1,169,779	6,285,432

adequate regeneration, and will likely require site preparation with either heavy machinery or herbicides. The use of heavy equipment often means shearing and windrowing, or bulldozing and windrowing. The latter practice is frequently used on private lands; thus, 120,059 acres of this condition are subject to bulldozing and windrowing. Better utilization and management throughout the rotation on these lands would allow low-risk management practices to be used, resulting in less soil and water impact and less cost.

About 43,585 acres of oak-pine type were harvested and artificially regenerated, and 140,865 acres were harvested and regenerated naturally. An adequate stocking of pine may occur on many sites but the hardwood component is dominant. A large portion of this land may need release work to maximize pine yields. Herbicide release will not adversely affect soil and water, if carefully applied. If the pine is of sufficient age and height, prescribed fire can control hardwood competition, with minimal impacts on soil and water. If the goal on these lands is pine management, control of competition is best performed during the rotation, rather than after harvest because large hardwoods require shearing and windrowing, which have soil and water impacts. Eliminating competition during rotation and keeping hardwood stems small allows a low-risk site preparation treatment after harvest, significantly reduces soil and water impacts during regeneration, and probably reduces the total soil and water impacts for the rotation even with periodic fire.

Degree of Erosion

Data were collected on the degree of erosion for each plot. Erosion was classified as none, light, medium, and high. Light erosion represented a small amount of sheet erosion; medium, both sheet and rill erosion; and high, large rill and gully erosion. The classification was based on the amount of erosion occurring at the time the plot was visited. Coupling the degree of erosion with past treatment or disturbance provides information for analyzing the impacts of recent treatments and disturbances on present erosion (table 5). Because the Coastal Plain is relatively flat and has soils with low erosion potential, recent activities or disturbance result in little erosion. From 88 to 98 percent of the area associated with each treatment or disturbance was not undergoing erosion when the plots were visited. For untreated or undisturbed conditions, 68,690 acres were eroding to a light degree, probably reflecting sandhill soils with some exposed sand even in natural conditions. Using erosion data contained in the Southern Region Erosion Data Bank (Dissmeyer and Stump 1978), it would be possible to assign approximate erosion rates to each of the conditions in table 5 and estimate the erosion volume for each condition and the total erosion occurring in the Coastal Plain.

The Piedmont has rolling topography, steeper slopes, and soils with higher erosion potential. Therefore management activities and disturbances in the Piedmont can be expected to have medium to high erosion (table 5). Depending on the condition, 62 to 86 percent of the area was not eroding. Approximately 14 percent of the forest is undergoing light erosion; 5 percent, medium; and 4 percent, high.

When South Carolina is resurveyed, new data on degree of erosion can be compared with these data for trends in erosion impacts of various treatments or disturbances. South Carolina is implementing their Best Management Practices (BMP) for Water Quality Management under the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500). FIA data on degree of erosion and its trend over time can provide useful information for monitoring the effectiveness of the BMP implementation program.

Grazing

Grazing is viewed in two ways by foresters: (1) as being detrimental to tree growth, or (2) as an opportunity for multiple use of forest lands. Questions are raised about erosion and compaction caused by cattle in the woods. Table 5 indicates that erosion is associated with grazing, with most of it found in the Piedmont; however, most grazing has no associated erosion.

A closer analysis of grazing suggests that there are areas where grazing causes excessive erosion and compaction. Four classes of grazing intensity were used in the survey:

None

Light grazing--less than 35 percent of the plants grazed

Table 5.--Degree of erosion associated with selected past treatments and disturbances of commercial forest land in South Carolina

Past treatment or disturbance	Total	Degree of erosion			
		None	Light	Medium	High
	Acres				
COASTAL PLAIN					
None	3,950,416	3,870,938	68,690	5,424	5,364
Harvest with artificial regeneration[a]	288,146	265,363	19,986	2,797	--
Harvest without artificial regeneration[a]	444,095	425,042	19,053	--	--
Other harvest[a]	607,321	579,984	25,037	2,300	--
Intermediate cutting[a]	1,135,474	1,095,214	38,800	--	1,460
Artificial regeneration[a]	67,259	64,885	2,374	--	--
Natural disturbance[b]	366,951	355,118	9,355	2,478	--
Prescribed burning[c]	2,097,756	2,028,167	57,044	6,009	6,536
Grazing[c]	276,616	242,358	28,249	6,009	--
PIEDMONT					
None	2,335,016	1,899,410	247,251	82,400	105,955
Harvest with artificial regeneration[a]	143,023	101,347	22,646	15,871	3,159
Harvest without artificial regeneration[a]	347,232	279,317	47,410	20,505	--
Other harvest[a]	216,345	170,416	38,112	7,817	--
Intermediate cutting[a]	750,692	643,315	68,500	13,890	24,987
Artificial regeneration[a]	69,534	50,001	4,370	15,163	--
Natural disturbance[b]	365,285	270,248	46,751	19,525	28,761
Prescribed burning[c]	180,608	120,510	35,758	12,281	12,059
Grazing[c]	465,656	290,825	104,817	51,114	18,900

[a]Primary treatment code.

[b]Includes damage from diseases, insects, weather, and other natural destructive agents (excluding fire).

[c]Identified by any past treatment or disturbance code.

Moderate grazing--35 to 70 percent of the plants grazed

Heavy grazing--70+ percent of the plants grazed

Compaction was determined by recording the percentage of the plot that was compacted. The area computation was judged by visual evidence; that is, hoofprints, wheel tracks, and other associated disturbances. The area affected was estimated.

By broad timber types, the area experiencing erosion under various grazing intensities is given in tables 6 and 7. In the Coastal Plain, the area grazed varies between 3.2 and 4.7 percent of the area in natural pine, oak-pine, and hardwood types, whereas only 0.6 percent of the pine plantations are grazed. In the Piedmont, grazing

was found in 2.7 percent of the pine plantation area and ranged from 9.5 to 12.7 percent for the natural pine, oak-pine, and hardwood types. Apparently, landowners are keeping cattle out of their pine plantations to protect their investments. Possibly landowners perceive cattle and pine plantations as incompatible. Heavier grazing in the other timber types probably reflects a low appreciation for such timber lands and a low level of timber management.

Grazing with moderate intensity was found on 208,368 acres in South Carolina. Heavy grazing occurred on 82,384 acres (tables 6, 7). Were these two classes of grazing intensity causing any soil, water, or timber growth problems? A partial answer can be found by analyzing how much soil compaction is associated with each class of grazing intensity by timber type (table 8). With the exception of oak-pine types, heavy grazing compacted an average area by

Table 6.--Area of commercial forest land undergoing erosion associated with grazing in the Coastal Plain of South Carolina, by timber type

Timber type and grazing intensity	All classes	Degree of erosion			
		None	Light	Medium	High
			Acres		
Pine plantations					
None	949,616	917,828	28,991	2,797	--
Light	2,741	2,741	--	--	--
Moderate	3,230	3,230	--	--	--
Total	955,587	923,799	28,991	2,797	--
Natural pine					
None	2,254,104	2,224,913	25,523	--	3,668
Light	60,652	52,593	5,191	2,868	--
Moderate	28,405	25,175	3,230	--	--
Heavy	16,319	16,319	--	--	--
Total	2,359,480	2,319,000	33,944	2,868	3,668
Oak-pine					
None	995,396	954,806	34,780	2,942	2,868
Light	25,949	19,841	6,108	--	--
Moderate	16,367	10,140	6,227	--	--
Heavy	7,232	7,232	--	--	--
Total	1,044,944	992,019	47,115	2,942	2,868
Hardwoods					
None	3,499,138	3,389,893	98,029	7,260	3,956
Light	66,844	63,975	2,869	--	--
Moderate	35,450	33,138	2,312	--	--
Heavy	13,427	7,794	2,312	3,141	--
Total	3,614,859	3,494,980	105,522	10,401	3,956
All types					
None	7,698,254	7,487,440	187,323	12,999	10,492
Light	156,186	139,150	14,168	2,868	--
Moderate	83,452	71,683	11,769	--	--
Heavy	36,978	31,525	2,312	3,141	--
Total	7,974,870	7,729,798	215,572	19,008	10,492

Table 7.--Area of commercial forest land undergoing erosion associated with grazing in the Piedmont of South Carolina, by timber type

Timber type and grazing intensity	All classes	Degree of erosion			
		None	Light	Medium	High
	Acres				
Pine plantations					
None	395,030	340,967	36,593	14,311	3,159
Light	10,900	--	5,066	5,834	--
Total	405,930	340,967	41,659	20,145	3,159
Natural pine					
None	1,675,115	1,379,288	156,679	60,635	78,513
Light	121,481	65,301	47,071	--	9,109
Moderate	35,135	30,765	--	--	4,370
Heavy	18,192	18,192	--	--	--
Total	1,849,923	1,493,546	203,750	60,635	91,992
Oak-pine					
None	587,987	465,686	71,597	21,208	29,496
Light	38,543	38,543	--	--	--
Moderate	42,410	24,170	13,870	4,370	--
Heavy	4,660	--	4,660	--	--
Total	673,600	528,399	90,127	25,578	29,496
Hardwoods					
None	1,404,248	1,140,444	154,148	58,683	50,973
Light	124,410	70,969	22,176	25,844	5,421
Moderate	47,371	34,636	7,314	5,421	--
Heavy	22,554	8,249	4,660	9,645	--
Total	1,598,583	1,254,298	188,298	99,593	56,394
All types					
None	4,062,380	3,326,385	419,017	154,837	162,141
Light	295,334	174,813	74,313	31,678	14,530
Moderate	124,916	89,571	21,184	9,791	4,370
Heavy	45,406	26,441	9,320	9,645	--
Total	4,528,036	3,617,210	523,834	205,951	181,041

86 percent or more. Generally, soil compaction increases with increasing grazing intensity. The moderate grazing class had soil compaction averaging between 37 and 81 percent of the area. The 81 percent compaction for hardwoods in the Piedmont approaches the heavy grazing class. If compaction were judged unacceptable when the area compacted exceeds 60 percent, then grazing pressure would need to be reduced on 122,523 acres (tables 6, 7).

Another method for judging the acceptability of woodland grazing is to compare degree of erosion with grazing intensity. In the Piedmont, medium to high erosion was found on 70,014 acres of forest grazed to various intensities (table 7). In the Coastal Plain, there are 6,009 acres of grazed forest with medium erosion (table 6). The data do not suggest any relationship between grazing intensity and degree of erosion. Most of the medium to high erosion was associated with light grazing. None of the heavy grazing observed was associated with high erosion.

The poor correlation of erosion with grazing intensity is probably the result of several factors. One possible explanation is

Table 8.--Soil compaction of South Carolina commercial forest land, by grazing intensity and timber type

Grazing intensity	Pine plantations	Natural pine	Oak-pine	Hardwoods
	- - - - Percent of area - - - -			
	COASTAL PLAIN			
None	11	5	6	7
Light	(a)	23	19	12
Moderate	(a)	49	42	38
Heavy	--	97	55	99
	PIEDMONT			
None	25	10	11	9
Light	11	44	37	39
Moderate	--	59	37	81
Heavy	--	86	(a)	96

[a]Insufficient data for evaluation (1 plot only).

that light grazing can occur in areas that have been logged or site prepared, thus the medium to high erosion is a reflection of more than one disturbance, grazing being one of them. Heavy grazing on gentle slopes and stable soils can result in little erosion. Also, light grazing may occur in seriously eroding areas such as old gully systems, where any disturbance will add to the high degree of erosion.

However, there are 76,023 acres of forest land with medium to high erosion associated with grazing should be reduced or eliminated on these sensitive areas. If the primary cause of erosion is from another disturbance, grazing the invading weeds and grasses will slow the healing process.

Burn History

The total acreage of forest burned each year is difficult to determine by fire and forest resource planners. Reliable data usually are available for wildfire, but the area treated by prescribed fire is difficult to ascertain. FIA crews recorded if and when the stand was burned, but no attempt was made to classify a burn as wildfire or prescribed fire. The area of prescribed fire can be approximated by subtracting the area of wildfire, determined by the State Forester's office, from the FIA total for the State.

FIA data enable an analysis of fire occurrence to be made by timber type (table 9). Because prescribed fire is used to control hardwood competition in pine types, FIA data reveal that the heaviest concentration of fire is in pine plantations and natural pine stands, which is especially true for the Coastal Plain.

To control hardwoods, prescribed fire should be used every 3 to 7 years. The area burned, by time period, is given in table 9. In the past 10 years, approximately 40 percent of the pine plantations and the natural pine stands has been burned in the Coastal Plain, whereas only 13 percent of the pine plantations and 3 percent of the natural pine stands have been burned in the Piedmont. Prescribed fire is concentrated in the Coastal Plain. Apparently, there is little effort to control hardwoods in pine stands in the Piedmont.

Fire occurrence by stand age provides useful information. The percentage of plots burned during the past 10 years by stand age and timber type is depicted by figure 6. The incidence of fire is fairly constant for pine plantations and natural pine stands through all age classes in the Coastal Plain (fig. 6A), with an average of 40 percent burned in each age class. The 50 percent occurrence for the first age class for pine plantations probably reflects the use of prescribed fire in site preparation. The incidence of fire decreases with stand age for oak-pine and for hardwoods.

In the Piedmont, data suggest that prescribed fire is not widely used to control hardwood competition in older stands of natural pine or pine plantations (fig. 6B).

In both the Piedmont and Coastal Plain, the high incidence of fire in young stands of hardwoods probably reflects prescribed fire as a site preparation treatment. However, some pine plantations failed and hardwoods dominate the sites.

Fire in the Coastal Plain does not expose a great deal of soil (fig. 7A). Once burned, the area essentially healed in about 2 years, and erosion is minimal because of gentle terrain and stable soils. Fire in the Piedmont appears to expose a little more soil, but burns heal rapidly (fig. 7B). The Piedmont has steeper slopes and more erodible soils than the Coastal Plain, thus higher erosion rates can be expected. Based on the small amount of exposed soil, however, erosion rates are minimal.

Table 9.--Area of commercial forest burned in South Carolina, by age of fire and timber type

Timber type	Age of fire			Burn per year[a]	Area of timber type
	1 year	1-3 years	3-10 years		
	Acres				
COASTAL PLAIN					
Pine plantations	51,818	116,954	206,714	37,549	955,587
Natural pine	149,667	351,265	462,828	96,376	2,359,480
Oak-pine	40,679	59,980	192,361	29,302	1,044,944
Hardwoods	58,229	141,236	266,025	46,549	3,614,859
Total	300,393	669,435	1,127,928	209,776	7,974,870
PIEDMONT					
Pine plantations	--	18,570	35,118	5,369	405,930
Natural pine	13,532	17,162	26,399	5,709	1,849,923
Oak-pine	--	6,922	5,200	1,212	673,600
Hardwoods	21,513	16,001	20,191	5,771	1,598,583
Total	35,045	58,655	86,908	18,061	4,528,036

[a]Average burn per year for the previous 10 years.

Accessibility

The accessibility to a stand by men and equipment was analyzed and classified as follows:

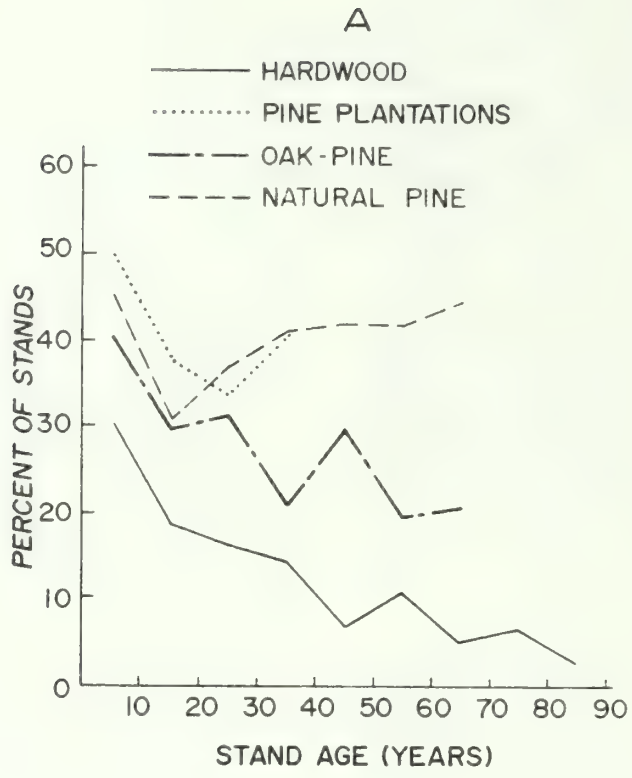
1. The forest area is highly accessible by using existing roads.
2. Roads were or could be easily built into the area.
3. Roads were or would be difficult to build into the area.
4. Roads were or would be very difficult or impractical to build into the area due to slope, water, or other physical obstacles.

The area of commercial forest land treated or disturbed is given by accessibility class in table 10. For both the Coastal Plain and the Piedmont, accessibility was an important determinant of whether the stand was treated or disturbed. In the Coastal Plain, only 19 and 14 percent of the areas where roads were either difficult or very difficult to build, respectively, were treated or disturbed during the last remeasurement period. Accessibility in the Coastal Plain is excellent, with 96 percent of the area either highly accessible or with roads easily built into the area. The same general situation and relationship to past activity was found in the Piedmont.

Building roads into difficult areas can have negative impacts on watershed conditions. Only a small percentage of the statewide area has accessibility problems, thus reducing the impact of roads on water quality and watershed condition.

Operability

Operability is the limitation that water conditions, excessive slope, badly broken terrain, or other adverse nonvegetative conditions have on the ability of men and equipment to work in a forest environment.



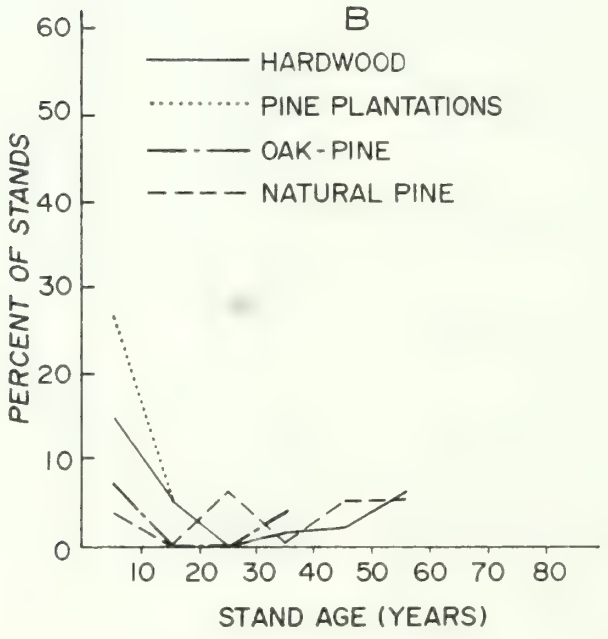


Figure 6.--Stands burned during the last 10 years in the Coastal Plain (A) and in the Piedmont (B).

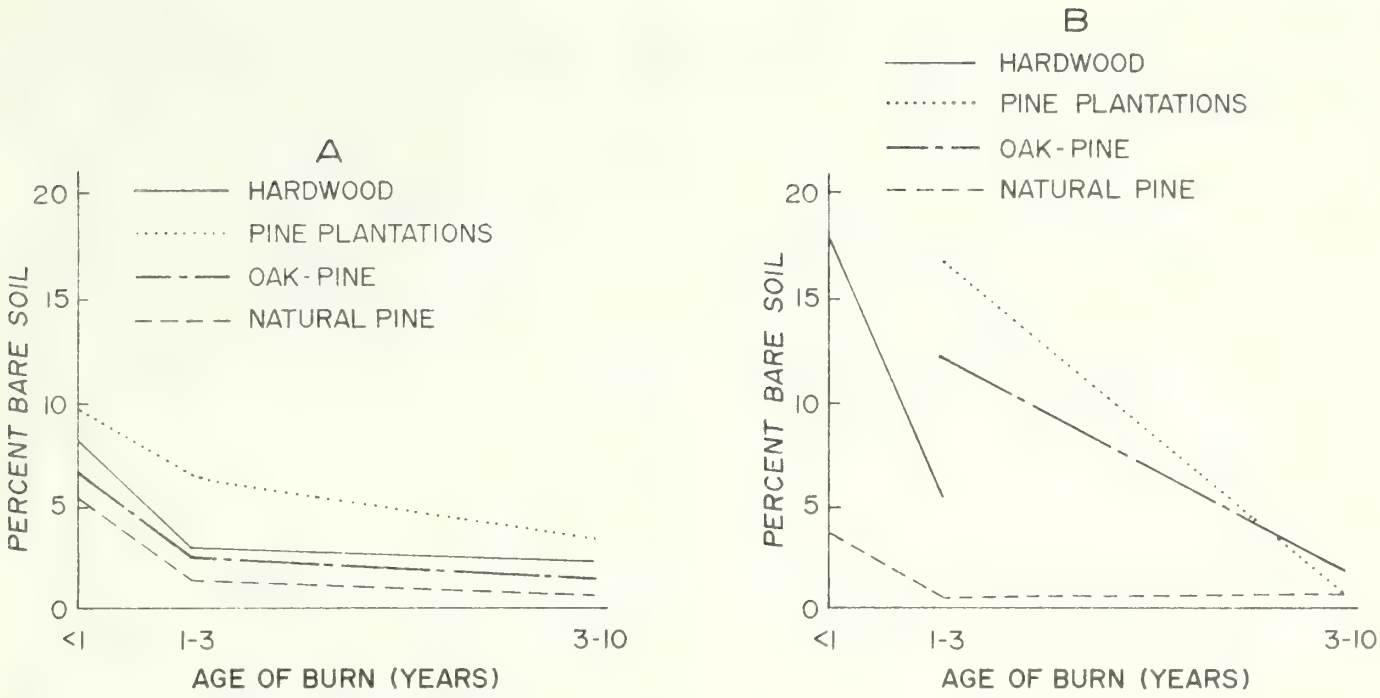


Figure 7.--Bare soil recovery from burns in the Coastal Plain (A) and in the Piedmont (B).

Table 10.--Area of commercial forest land treated or disturbed in the Coastal Plain and Piedmont of South Carolina, by accessibilty class

Condition	All classes	Highly accessible	Roads easily built	Roads difficult to build	Roads very difficult to build
			Acres		
			COASTAL PLAIN		
Treated or disturbed	4,024,454	3,503,088	472,791	31,340	17,235
Total area	7,974,870	6,454,384	1,239,205	160,995	120,286
			PIEDMONT		
Treated or distrubed	2,193,020	1,760,925	411,812	12,979	7,304
Total area	4,528,036	3,504,918	958,934	51,197	12,987
			STATEWIDE		
Treated or disturbed	6,217,474	5,264,013	884,603	44,319	24,539
Total area	12,502,906	9,959,302	2,198,139	212,192	133,273

Operability of the landscape has a direct influence on potential impacts on watershed conditions, soil compaction, erosion, sedimentation, and water quality. Seven operability classes were used in this study:

1. No problem under normal conditions
2. Limited to seasonal use due to water conditions in wet weather
3. Moderate slopes averaging 20 to 39 percent, irregular terrain, or other ground conditions that limit the type of equipment which could be operated within the forest conditions
4. Mixed wet and dry areas within forest condition typical of multichanneled streams with intermixed dry areas or islands
5. Severe slopes averaging 40 to 49 percent, broken terrain, or other adverse ground conditions which drastically limit equipment use
6. Adverse operating conditions caused by year-round water problems
7. Slopes of 50 percent or more

Operability appears to be limiting when mixed wet and dry areas, severe slopes, year-round water, and slopes more than 50 percent are encountered in both the Coastal Plain and the Piedmont (table 11). None of the other conditions appears to restrict forest management activities. When slopes exceed 50 percent, the area is generally avoided, thus avoiding some potentially severe watershed problems. Operability for the vast majority of the State is reasonably good to excellent and forestry operations performed with reasonable care will not adversely affect watershed conditions or water quality.

Treatment Opportunity

Timber Type

One way to analyze treatment opportunity is by timber type (table 12). This combination of data provides better interpretation for types of practices which might be employed and the potential area of such practices. Approximately 355,710 acres of oak-pine and upland hardwood types need conversion to pine, and 1,141,314 acres need artificial regeneration after site preparation. This area is interpreted as having a large quantity of undesirable hardwoods requiring treatment before planting pine. Again, shearing and windrowing is a common practice for these conditions. The total area involved is 1,497,206 acres and, if all are treated by shearing and windrowing,

Table 11.--Area of commercial forest land treated or disturbed in South Carolina, by operability class

Condition	All classes	No problem	Limited seasonally	Moderate slopes	Mixed wet and dry area	Severe slopes	Water problems	Slopes 50% +
				Acres				
				COASTAL PLAIN				
Treated or disturbed	4,024,454	3,376,037	542,527	50,118	22,952	2,558	30,262	--
Total area	7,974,870	5,709,202	1,808,560	116,976	101,041	10,524	226,022	2,545
				PIEDMONT				
Treated or disturbed	2,193,020	1,666,718	53,684	424,101	10,064	30,164	3,918	4,371
Total area	4,528,036	3,233,823	182,004	911,115	13,512	132,049	3,918	51,615
				STATEWIDE				
Treated or disturbed	6,217,474	5,042,755	596,211	474,219	33,016	32,722	34,180	4,371
Total area	12,502,906	8,943,025	1,990,564	1,028,091	114,553	142,573	229,940	54,160

Table 12.--Treatment opportunity in South Carolina, by timber type

Treatment opportunity	Total area	Pine plantations	Natural pine	Oak-pine	Upland hardwoods	Lowland hardwoods
	Acres					
No treatment	7,634,690	1,079,787	3,010,284	986,629	1,497,206	1,060,784
Salvage cut	115,871	29,373	54,368	6,207	5,631	20,292
Harvest	741,494	3,229	158,587	61,154	141,878	376,646
Commercial thinning	486,422	158,285	245,767	11,981	7,376	63,013
Precommercial thinning	72,458	5,701	50,944	4,055	2,797	8,961
Cleaning, release, or intermediate cut	811,829	20,593	237,611	178,232	221,855	153,538
Stand conversion	508,901	6,115	58,742	106,832	248,878	88,334
Artificial regeneration w/o site preparation	72,582	10,174	17,280	--	41,773	3,355
Artificial regeneration w/ site preparation	2,058,659	48,260	375,820	363,454	777,860	493,265
Total	12,502,906	1,361,517	4,209,403	1,718,544	2,945,254	2,268,188

significant impacts in watershed condition, erosion, soil productivity, and water quality can be expected. Alternative methods should be used which will minimize impacts as this land is brought into production. One alternative is harvesting some stands for wood energy or for pulpwood by whole-tree chipping. In many cases, whole-tree chipping would be sufficient site preparation to establish pine. Watershed impacts of whole-tree chipping are generally light.

If whole-tree chipping is impractical, the use of herbicides is an option to explore. After the hardwood overstory is killed, areas can be underplanted with pine. With careful use of herbicides, watershed and water quality impacts should be slight.

Artificial regeneration after site preparation in pine plantation and natural pine stands probably reflects recent logging and a stand of noncommercial stems (table 13). Frequently, these stands can be chopped, or chopped and burned to prepare the site for pine seedlings. Both of these treatments have low risks for soil and water, if implemented with care. However, some stands may have numerous large stems requiring herbicide injection or shearing and windrowing. There are 424,080 acres in this condition and their treatment will have a significiant impact on watersheds.

Operability

For the area needing treatment, operability is most limited by mixed and dry conditions, severe slopes, year-round water, and slopes more than 50 percent for both the Coastal Plain and the Piedmont (table 13). Nearly 2 million acres have limited operability due to water; that is, seasonal water problems in the Coastal Plain and Piedmont. Approximately 332,000 acres need harvesting. Logging during the wet season can compact soil, and compaction is known to reduce tree growth. Therefore, harvesting should be scheduled when the threat of compaction is minimal.

Approximately 464,000 acres which have limited operability due to seasonal water problems in the Coastal Plain and the Piedmont need regeneration or conversion. Shearing and windrowing, or bulldozing involves repeated trips over the soil surface, thus compacting a very high percentage of the soil. The degree of compaction is influenced by the soil moisture content; to minimize compaction, site preparation should be performed when the soil is relatively dry.

Table 13.--Area of commercial forest land in South Carolina, by treatment needed and by operability class

Treatment needed	All classes	No problem	Limited seasonally	Moderate slopes	Mixed wet and dry area	Severe slopes	Water problems	Slopes 50% +
				Acres				
				COASTAL PLAIN				
None	4,411,679	3,333,888	901,298	44,444	49,707	6,266	73,531	2,545
Harvest or salvage	608,997	201,796	299,851	15,356	12,379	--	79,615	--
Thinning or intermediate cut	840,073	628,103	164,402	10,227	15,217	--	22,124	--
Regeneration or conversion	2,114,121	1,545,415	443,009	46,949	23,738	4,258	50,752	--
Total	7,974,870	5,709,202	1,808,560	116,976	101,041	10,524	226,022	2,545
				PIEDMONT				
None	3,223,011	2,326,400	107,118	672,727	4,998	96,845	--	14,923
Harvest or salvage	248,368	120,006	32,040	50,829	--	18,428	--	27,065
Thinning or intermediate cut	530,636	427,794	21,970	63,663	5,066	12,143	--	--
Regeneration or conversion	526,021	359,623	20,876	123,896	3,448	4,633	3,918	9,627
Total	4,528,036	3,233,823	182,004	911,115	13,512	132,049	3,918	51,615

Chopping or chopping and burning do not compact the soil as much as shearing and windrowing and would be preferred. If shearing and windrowing is needed to remove a heavy stand of cull hardwoods, the risk of soil compaction is high. Where compaction exists, disking or bedding tills the soil, which break up the compacted soil. Disking and bedding should be restricted to gentle slopes to minimize erosion and water quality impacts.

Under the heading "water problems," 156,409 acres need harvesting, salvage, thinning, regeneration, or conversion (table 13). With year-round water problems, if not already drained, this area will probably need drainage to operate with minimal damage to the soils. In the Coastal Plain, 50,752 acres need regeneration or conversion in these wet sites, which probably means that bedding is the most likely site preparation practice to use (table 13). Some of these soils are also phosphorus deficient and require fertilization to gain satisfactory growth. Bedding alone, or in combination with phosphorus fertilization, are needed to improve soil productivity on a large portion of this area.

In the Piedmont, 27,065 acres that have slopes in excess of 50 percent need harvest or salvage cuts. Some mountainous land is included in this category, and logging these steep lands with tractors or rubber-tire skidders can cause excessive soil erosion and water quality impacts. Portable cable logging systems, which cause minimal soil and water impacts, are available and should be considered for logging this steep land.

Environmental Laws and Regulations

Potential Effect on Timber Resources

The Federal Clean Water Act (PL 92-500) of 1972 and 1977 called for the development of best management practices (BMP). How much timber land is potentially affected by these regulations? FIA data give some information for answering this question (table 14). Here the area of forest is listed by stand volume, ownership, and physiographic class. Physiographic classes included:

Sandhills. Rolling uplands of deep sand with level areas broken by gentle slopes and small drains.

Flatwoods and dry pocosins. Flat or fairly level areas ordinarily with sandy soil, which are somewhat dry throughout much of the year.

Rolling uplands. Well-drained, rolling uplands with level areas broken by gentle slopes and numerous small drains. (Excludes deep sands.)

Narrow stream margins. Low, moist, fertile areas along small streams. These sites are normally well drained but flooding might occur during short periods of excessive rainfall.

Broad stream margins. Broad, moist bottom land forming the margins of large streams. These sites are normally well drained, but flooding might occur during short periods of excessive rainfall. These sites are rich in alluvial deposits.

Deep swamps. Large, low, wet, flat forested areas which are flooded for long periods of time. Most of the large, poorly drained stream margins fall into this class. Soil and moisture conditions on these sites are generally quite favorable for forest growth of restricted species.

High mountaintops and slopes. Elevations in the Southern Appalachians more than 5,000 feet. These sites are characterized by steep slopes, rock outcrops, natural balds, exposure to severe climatic conditions, and short growing seasons.

FIA considered other physiographic classes which are combined in a miscellaneous category in table 14.

A BMP often included in water quality management plans is streamside management zones (SMZ). Narrow stream margins may closely approximate the area that might be included in SMZ. The timber volume affected is considerable and is reflected by 645,554 acres of narrow stream margins having stand volumes exceeding 5,000 board feet per acre; 385,188 acres with 1,500 to 5,000 board

Table 14.--Area of commercial forest land in South Carolina, by ownership class and stand volume (board feet), and by physiographic class

Ownership class and stand volume per acre	All classes	Deep swamps	Broad stream margins	Narrow stream margins	Mountain tops	Flatwoods and dry pocosins	Bays and wet pocosins	Rolling uplands	Sandhills	Other misc. classes
	Acres									
National Forest										
Less than 1,500	99,696	--	--	--	--	34,753	2,482	62,461	--	--
1,500 to 5,000	125,694	--	--	11,657	27,796	42,695	15,058	28,488	--	--
5,000+	353,334	15,557	3,010	49,753	27,796	75,793	27,470	151,471	--	2,483
Subtotal	578,724	15,557	3,010	61,410	55,593	153,241	45,010	242,420	--	2,483
Other public										
Less than 1,500	197,489	2,920	2,055	6,098	--	38,242	4,523	38,546	101,811	3,294
1,500 to 5,000	148,853	2,920	--	8,536	--	50,729	5,413	32,230	41,803	7,222
5,000+	165,761	2,796	9,755	25,556	2,580	47,479	1,461	43,307	26,136	6,691
Subtotal	512,103	8,636	11,810	40,190	2,580	136,450	11,397	114,083	169,750	17,207
Forest industry										
Less than 1,500	1,108,896	4,314	10,689	19,956	--	486,935	60,820	400,192	116,181	9,809
1,500 to 5,000	473,107	26,442	20,859	39,845	--	214,118	44,344	99,994	20,670	6,835
5,000+	660,577	123,981	70,124	72,054	--	244,254	27,602	106,890	--	15,672
Subtotal	2,242,580	154,737	101,672	131,855	--	945,307	132,766	607,076	136,851	32,316
Farmer and other private										
Less than 1,500	3,208,556	15,973	24,563	162,342	40,696	813,245	91,656	1,457,074	549,561	53,446
1,500 to 5,000	3,037,370	41,155	67,577	325,150	43,668	845,042	64,621	1,402,985	198,699	48,473
5,000+	2,923,573	164,744	154,281	498,191	37,621	996,458	96,556	868,375	47,738	59,609
Subtotal	9,169,499	221,872	246,421	985,683	121,985	2,654,745	252,833	3,728,434	795,998	161,528
All ownerships										
Less than 1,500	4,614,637	23,207	37,307	188,396	40,696	1,373,175	159,481	1,958,273	767,553	66,549
1,500 to 5,000	3,785,024	70,517	88,436	385,188	71,464	1,152,584	129,436	1,563,697	261,172	62,530
5,000+	4,103,245	307,078	237,170	645,554	67,998	1,363,984	153,089	1,170,043	73,874	84,455
Total	12,502,906	400,802	362,913	1,219,138	180,158	3,889,743	442,006	4,692,013	1,102,599	213,534

feet; and 188,396 acres with less than 1,500 board feet. Management within SMZ is modified to protect streams, water quality, streambanks, and fisheries. Therefore, the management of considerable timber is affected by this one BMP.

A portion of broad stream margins is also affected by SMZ. Broad stream margins contain 362,913 acres of forest. Only the area nearest the stream channel will be affected by SMZ. FIA data indicate that 26,251 acres lay within 119 feet of the channel and approximately 11,030 acres occur within 50 feet. Therefore, an additional 11,030 to 26,251 acres of forest management will be affected by SMZ.

Water quality management plans have an implementation section which identifies steps to take and the groups of people to work with to install BMP. Table 14 indicates that 78 percent of the narrow and broad stream margins are owned by farmers and other private landowners, 15 percent by forest industry, 4 percent by the USDA Forest Service, and 3 percent by other public agencies. The last three categories represent 22 percent of the area, but have relatively few landowners compared with the vast number of farmers and private landowners. The big challenge in implementing SMZ will be to reach the farmers and private landowners.

Conclusions

FIA data when coupled with secondary data provide resource planners with information to evaluate watershed conditions, erosion volumes, water yields, and soil productivity impacts during the last remeasurement period and to project future management and its soil and water impacts. When the State is resurveyed in the future, FIA data will reveal trends in management practices, in watershed condition, water yield, erosion and sedimentation rates, soil productivity, and the relative health of the soil and water resource.

In South Carolina, forest watershed conditions are generally good, with only a small area that may be undergoing excessive erosion, soil compaction, and water quality impacts resulting from site preparation, roads, and grazing during the last remeasurement period. Generally, forest operations were conducted where land was accessible by roads and on lands that had good operability for most or all the year.

Future treatment needs generally occur on lands having good accessibility and operability. With proper and carefully implemented management practices, future watershed impacts should be low for most of South Carolina. There is a small area of land with poor accessibility and operability which is subject to serious watershed damage. Special forest management practices, such as cable logging, should be considered in harvesting. A very large area has been identified for stand conversion or regeneration. The site preparation method used for conversion or regeneration will significantly determine the future health of the watersheds and timber production as influenced by soil compaction and erosion.

FIA data reveal a large area of forest subject to environmental laws. The management of a large volume of timber is affected by streamside management zones.

When South Carolina is resurveyed in the future, FIA data might reveal trends in erosion and other watershed conditions. These data will prove useful in monitoring the effectiveness of programs for implementing environmental laws.

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KEYWORDS: Watershed management, soils, hydrology, timber management.

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Weight and Volume of Plantation-Grown Choctawhatchee Sand Pine

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October 1985

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Weight and Volume of Plantation-Grown Choctawhatchee Sand Pine

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ABSTRACT

The aboveground green weight of the total tree and its major components, the main stem and crown, were determined in eight stands of planted Choctawhatchee sand pine ranging in age from 7 to 27 years. Eighty-three trees, ranging in d.b.h. from 0.7 to 11.1 inches and from 11 to 59 feet in total height, were sampled. After testing for significant differences, data were stratified to provide two sets of composite equations: one for the six stands with a closed canopy, i.e., ages 12 to 27 years, and one for the young stands where crown closure had not yet occurred. Equations for predicting individual tree green and dry weights and cubic volumes of wood, and of wood and bark, were developed for the main stem and crown of each canopy class. Ratio equations were developed to allow estimation of weights and volumes to specified top stem diameter. Tables for estimating green and dry weight and cubic volume are given for the total tree and its major components, based on d.b.h. and total height.

Keywords: Pinus clausa var. immuginata, biomass, prediction equations.

The Choctawhatchee variety of sand pine (Pinus clausa var. immuginata D. B. Ward) is the preferred commercial timber species for reforestation of xeric, deep sand sites in northwest Florida (Brendemuehl 1981). In addition to the area in Florida where it is endemic, Choctawhatchee sand pine has been planted with good success on similar deep sand sites in Georgia and South Carolina (Hebb 1982; McNab and Carter 1981; Outcalt and Brendemuehl 1985) (fig. 1). Choctawhatchee sand pine can be used for sawtimber and plywood and is suitable for production of both bleached and unbleached kraft papers of high strength (Taras 1973).

As with other pine species, commercial measurement of harvested Choctawhatchee sand pine is typically estimated by using scaling factors to convert truck-load weight totals to conventional units of volume. Applicable scaling factors for plantation-grown Choctawhatchee sand pine, however, are not available, and conversion factors for other pine species must be used. In addition, there are no satisfactory equations for estimating standing tree volumes in plantations. The purpose of this Paper is to present summary tables and equations for estimating the aboveground weight and volume of various ages of Choctawhatchee sand pine planted at typical stand densities. Similar information is available for natural stands of Choctawhatchee sand pine (Taras 1980) but may not be applicable to plantations because of differences in form class, crown characteristics, and wood physical properties.

Procedures

Field Procedures

Eight Choctawhatchee sand pine plantations, two each of ages 7, 18, and 27, and one 12 and one 13 years old, were selected for sampling during May 1981, after the major portion of the current year's growth had occurred. All plantations were growing on excessively drained, infertile, sandy soils of the

[1] This research was completed when McNab was with the Utilization of Southern Timber Work Unit, Athens, Georgia.

[2] Now retired.

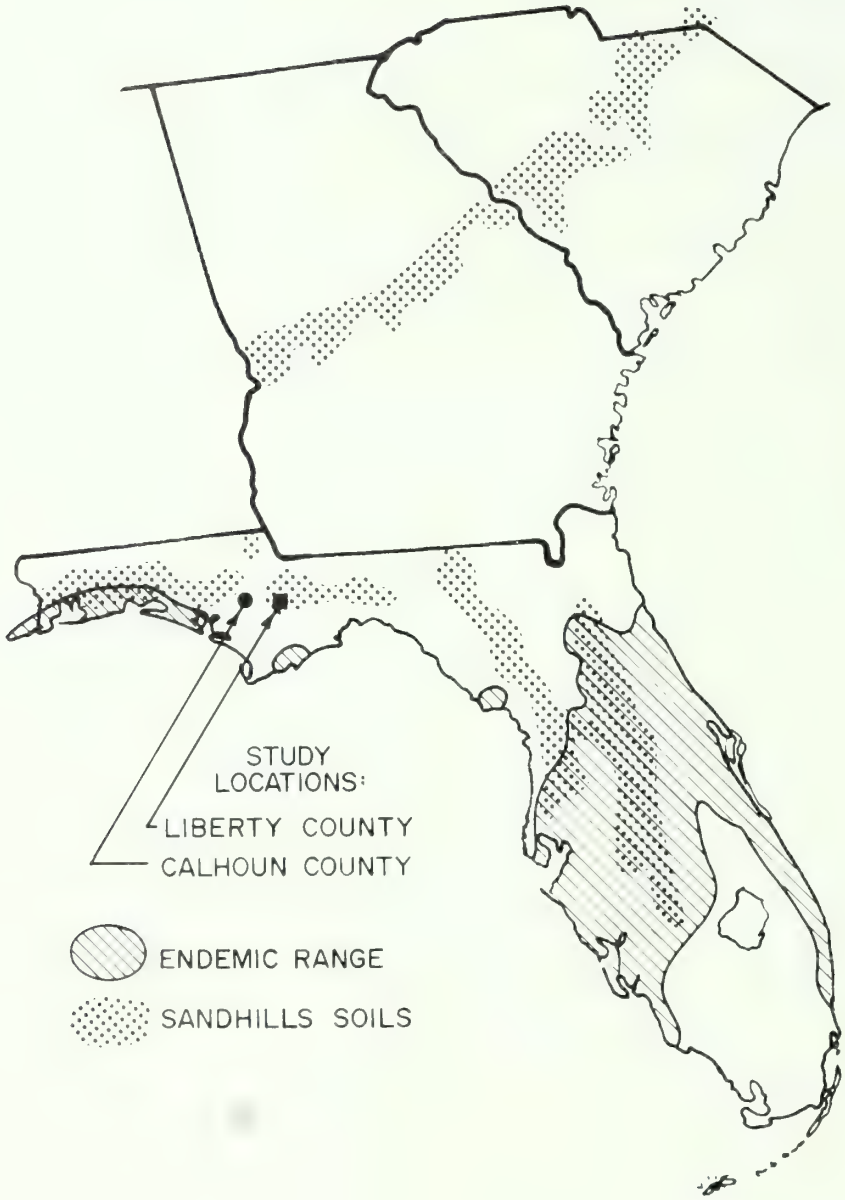

Figure 1.--The endemic range of sand pine (Pinus clausa) in Florida and sandhill soils in Georgia and South Carolina where the Choctawhatchee variety is also planted. The two study sites in Florida are shown.

Lakeland series, a thermic, coated Typic Quartzipsamment. These plantations had been established by similar site preparation and planting procedures. All seedlings originated from seed collected from natural stands of Choctawhatchee sand pine.

All plantations sampled were located in northwest Florida (fig. 1). The two 27-year-old plantations were in Liberty County, and the other six stands were in the Southeastern Forest Experiment Station's Chipola Experimental Forest, Calhoun County. Stocking and basal area of the sample stands were typical of other stands of similar age in northwest Florida (table 1). Site quality varied only slightly among the sample stands. At least 10 trees were selected for sampling in each of the eight stands to cover the range in d.b.h. and crown class. Table 2 gives means and ranges of sample-tree data by d.b.h. class for each age class. The two stands sampled in each of the two older age classes represented a low and high level of stocking.

After selection, sample trees were felled and measured. Each tree was separated into its two major components of main stem and crown. The main stem extended from the butt to 1-inch diameter outside bark (d.o.b.) and was marked at 7, 4, and 2 inches d.o.b. to simulate sizes of pine main stems typically harvested for merchantable products of sawtimber, pulpwood, and topwood, respectively. The length of each section was measured and then weighed on portable platform scales to the nearest 1/10 pound. The live crown was separated into lower, middle, and upper sections and each section was weighed. The main stem less than 1-inch d.o.b. was included in the upper crown section. Dead material was separated from all crown sections and combined for a single biomass component. Three sample whole branches were collected from each section to determine the ratio of needles to branch wood and bark.

Sample disks were collected from the stem and branches to determine physical properties of wood by laboratory analysis. Disks, each about 1.5 inches thick, were cut at the butt and at 5-foot intervals along the stem of each tree. Similar sample disks were cut from sample branches in each crown section and dead crown material. About 0.05 pound of current and previous year's needles were collected from each crown section and combined into a single sample. The disks and a needle sample were sealed in individual polyethylene bags and returned to the laboratory to determine specific gravity, moisture content, and bark content.

The diameter and weight of stem and branch disks were determined both with and without bark except for sample disks from dead branches, which were processed with bark attached. The proportion of bark was calculated on a green weight basis. After soaking for 2 to 3 days, specific gravity of wood and bark was determined from immersed green volume and dry weight (Heinrichs and Lassen 1970). The moisture content of wood, bark, and

Table 1.--Characteristics of planted Choctawhatchee sand pine stands sampled in northwest Florida

Age class (yr)	Stocking level	Basal area	Site quality[1]
	Trees/acre	Ft²/acre	
27	225	94	53
27	630	135	50
18	400	96	52
18	801	114	49
13	560	65	52
12	647	57	49
7	831	15	52
7	955	45	54

[1]Total height at 25 years.

Table 2.--Diameters and heights of sample planted Choctawhatchee sand pine trees, by age and d.b.h. class

D.b.h. class	Sample trees	D.b.h.		Total Height	
		Mean	Range	Mean	Range
	No.	- - - - Inches - - - -		- - - - Feet - - - -	
		7 YEARS			
0	1	0.70	--	11.0	--
2	16	2.05	1.0- 2.9	15.5	11-18
4	3	3.40	3.1- 3.7	21.2	21-21
		12 YEARS			
2	3	2.47	2.3- 2.6	21.0	19-22
4	5	4.06	3.2- 4.5	26.6	25-28
6	2	5.40	5.3- 5.5	29.0	29-29
		13 YEARS			
2	1	2.90	--	22.9	--
4	5	4.22	3.6- 4.9	30.8	25-34
6	4	5.68	5.3- 5.9	34.4	33-37
		18 YEARS			
2	1	2.80	--	34.0	--
4	7	4.03	3.0- 4.9	38.0	33-43
6	7	6.10	5.3- 6.8	42.4	40-45
8	6	7.93	7.2- 8.6	47.8	46-50
10	1	9.10	--	50.0	--
		27 YEARS			
2	2	2.75	2.6- 2.9	35.0	31-39
4	3	4.33	3.9- 4.9	45.7	39-52
6	6	5.98	5.3- 6.7	54.5	49-57
8	5	8.00	7.3- 8.8	58.2	54-63
10	4	9.60	9.0-10.6	58.8	57-60
12	1	11.10	--	59.0	--

needles was determined on a dry weight basis after drying the individual samples of each component to a constant weight at 217 °F. The ratio of needle to branch wood plus bark in each crown section was determined by drying sample branches, separating out the needles, and weighing the needles and the woody components. This ratio was then applied to the total weight of each crown section to estimate total dry needle weight.

Mean values of specific gravity, moisture content, and bark content for the stem were estimated by weighting disk sample values by the volume[3] of the section they represented. The weighted specific gravity and moisture content was then used to determine the green weight per unit volume as follows:

$$\text{Green weight per ft}^3 = [1+MC/100] \times SG \times C \quad (1)$$

where: MC = weighted moisture content in percent
SG = weighted specific gravity
C = weight of water per cubic foot (62.43 pounds)

The weighted value of specific gravity for each section was used to calculate dry weight per cubic foot:

$$\text{Dry weight per ft}^3 = SG \times C \quad (2)$$

The cubic volume of wood and bark in the stem were estimated by using dry weight and component weight per cubic foot:

$$\text{Component volume (ft}^3) = \frac{\text{component dry weight}}{\text{component dry weight per ft}^3}$$

Mean physical properties of wood and bark for each crown section was estimated from simple averages of branch disk samples. Total crown properties were determined by combining the three sections for each tree, with dry weight as a weighting factor. Only results concerning the total crown will be presented and discussed in this report. Weight and volume of wood and bark components in the total crown were calculated in a manner similar to that used for the stem.

Total-tree weight, volume, and physical properties were obtained by combining appropriate components and weighting by cubic volume.

Analysis

Linear regression equations with independent variables of d.b.h. squared times total height (D^2Th) were developed to predict green and dry weights and green volumes of wood and bark in the total tree and its components. Grouping the data into D^2Th classes and plotting the variance of Y over D^2Th indicated that the variance of predicted weights and volumes increased with increasing D^2Th. A logarithmic transformation (to the base 10) was used to obtain a relatively homogeneous variance that is assumed in regression analysis. Thus, regression coefficients for tree and component weights and volumes are calculated by using the equation:

$$\log Y = b_0 + b_1 \times \log(D^2Th) + e \quad (3)$$

where: Y = weight or volume of component
e = sampling error
b_0, b_1 = regression coefficients

When a logarithmic estimate is converted back into original units it is biased downward because the antilogarithm of the estimated mean gives the geometric rather than the arithmetic mean (Cunia 1964). To account for this bias, a correction factor was computed by a procedure described by Baskerville (1972) and applied to each equation. The form of the equation, including the correction factor, is:

$$Y = 10(b_0+b_1 \times \log(D^2Th) + [S^2(y.x) \times \log_e(10)]/2+e) \quad (4)$$

where: $S^2(y.x)$ = error mean square from regression analysis

[3] Computed by Smalian's formula.

Equation (4) was simplified to:

$$Y = a(D^2 Th)^{b_1} \qquad (5)$$

where: $a = 10^{(b + [S^2(y.x) \times \log_e(10)]/2)}$

Analysis of sample plot green weight and volume data revealed significant differences in slope and intercept for trees in young stands with open canopies compared with older trees on plots with closed canopies. No significant difference, however, was found between plots within a canopy class. Therefore, sample weight and volume data were pooled into two groups for analysis and presentation of results: (1) trees in young stands that had not reached crown closure, and (2) trees in closed-canopy stands.

In sampling over the range of diameters present in each stand, only single trees were measured in the 0-inch class[4] of open-canopy stands and the 12-inch d.b.h. class of trees in closed-canopy stands (table 1). Since inferences concerning a single tree could be misleading, these trees were included with the 2-inch and 10-inch d.b.h. classes, respectively, for presentation of results. The analysis of data was unaffected since measured d.b.h. of each sample tree was used as the independent variable.

Results

Main Stem Heights

Main stem lengths within a diameter class to the 4-inch and 2-inch d.o.b. points were about two times greater for trees growing in stands with a closed canopy compared with the young open-canopy plots (table 3). This is primarily due to the difference in ages of the trees. In the closed-canopy stands, height to a 4-inch top averaged about 6.2 feet in the 4-inch diameter class and increased to more than 40 feet for trees in the 10-inch d.b.h. class. Trees in the 8-inch d.b.h. class averaged 11.4 feet in height to a 7-inch d.o.b. top, hence most were too short for harvesting as a merchantable sawtimber product. All trees sampled in the 10-inch class, however, had at least one 16.3-foot saw log to a 7-inch d.o.b. top. None of the trees of sawtimber size had any defects, and d.o.b. at merchantable height was 7.0 inches. Girard form class[5] averaged 76 and ranged from 72 to 83 for the six sawtimber-size trees greater than 9.0 inches d.b.h.

Total-Tree Weights

Total-tree green weights above stump ranged from 37.1 pounds for 2-inch d.b.h trees to 1,059.9 pounds for 10-inch d.b.h. class trees. The proportion of total-tree weight in wood, bark, and needles varied with tree size. The proportion of total-tree weight in wood increased and the proportion of bark and needles decreased as tree size increased for Choctawhatchee sand pines sampled in stands with closed canopies (table 4). The average tree sampled in closed-canopy stands was 5.7 inches d.b.h. and contained 79 percent wood, 13 percent bark, and 8 percent needles on a green-weight basis. The proportion of needles was greater and the proportion of wood was less for young trees in open stands compared with older trees in closed-canopy stands. The proportion of tree dry weight by component differed only slightly from green-weight proportions primarily because of differences in moisture content.

Table 5 shows the breakdown of sampled trees into stem, branches, and needles. As tree size increased, the proportion of green weight in the stem generally increased, whereas the proportion in branches remained relatively constant. The proportion in needles decreased from 10 percent in 2-inch trees to about 5 percent in 10-inch trees. The average tree in a stand with closed canopy contained 75 percent of its green weight in the main stem, 17 percent in branches, and 8 percent in needles. By comparison, young trees in open-canopy stands contained about a third of their green weight in each component. Thus, a higher proportion of their green weight was in branches and needles, with less in the main stem.

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[4] D.b.h. range, 0.1 to 0.9 inches.

[5] D.i.b. at 17 feet/d.b.h.

Table 3.--Mean and range of d.b.h. and height to various d.o.b. top diameters for planted Choctawhatchee sand pine sampled in open- and closed-canopy stands

D.b.h. class (in.)	Sample trees	Mean d.b.h.	Stem height to d.o.b. of: 7 inches		4 inches		2 inches		1 inch		Total height	
			Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
	No.	Inch	- Feet -									
			OPEN									
2	17	1.97	--	--	0.6	--	5.1	1-8	9.1	1-13	15.4	11-19
4	3	3.40	--	--	2.2	2-3	10.5	9-12	15.0	14-16	21.0	21-21
			CLOSED									
2	7	2.66	--	--	--	--	11.8	7-22	20.4	13-33	26.7	19-39
4	20	4.13	--	--	6.2	1-15	22.4	13-40	28.6	19-46	34.5	25-52
6	19	5.90	2.1	1-4	21.5	10-37	33.0	20-48	37.6	24-52	43.2	29-57
8	11	7.96	11.4	4-24	33.8	25-47	42.8	35-55	47.1	40-59	52.5	46-63
10	6	9.50	21.4	17-29	40.8	35-45	48.4	41-51	52.6	45-56	57.0	50-60

Table 4.--Average green and dry weight of total tree and proportion of tree in wood, bark, and needles for planted Choctawhatchee sand pine sampled in open- and closed-canopy stands

D.b.h. class (in.)	Total green weight	Tree component proportions (green)			Total dry weight	Tree component proportions (dry)		
		Wood	Bark	Needles		Wood	Bark	Needles
	Lb	- - - - Percent - - - -			Lb	- - - - Percent - - - -		
				OPEN				
2	29.0	53.6	14.6	31.8	11.7	53.2	13.7	33.1
4	91.6	64.2	13.5	22.2	36.1	65.0	14.1	20.9
Mean	38.4	55.2	14.4	30.4	15.4	55.0	13.7	31.3
				CLOSED				
2	37.1	72.7	17.1	10.2	17.1	73.9	16.5	9.6
4	130.4	77.2	14.0	8.7	59.5	78.5	13.4	8.1
6	326.4	79.4	12.3	8.3	146.4	80.6	11.6	7.8
8	645.5	83.2	10.8	6.0	277.5	83.9	10.0	6.1
10	1059.9	84.7	10.1	5.2	479.8	85.6	9.2	5.2
Mean	357.6	79.2	12.9	7.9	159.1	80.2	12.2	7.6

Table 5.--Average green and dry weight of total tree and proportion of tree in the main stem[1] and crown (branches and needles) for planted Choctawhatchee sand pine sampled in open- and closed-canopy stands

D.b.h. class (in.)	Total green weight	Tree component proportions (green)			Total dry weight	Tree component proportions (dry)		
		Stem	Branches	Needles		Wood	Branches	Needles
	Lb	- - - - Percent - - - -			Lb	- - - - Percent - - - -		
				OPEN				
2	29.0	38.3	29.9	31.8	11.7	37.7	29.2	33.2
4	91.6	46.1	31.7	22.2	36.1	46.6	32.5	20.9
Mean	38.4	39.5	30.1	30.3	15.4	39.0	29.7	31.3
				CLOSED				
2	37.1	72.9	16.9	10.2	17.1	73.8	16.6	9.6
4	130.4	73.9	17.4	8.7	59.5	75.0	16.9	8.1
6	326.4	73.3	18.3	8.3	146.4	74.4	17.8	7.8
8	645.5	79.0	15.0	6.0	277.5	79.5	14.4	6.1
10	1059.9	77.6	17.2	5.2	479.8	78.7	16.1	5.2
Mean	357.6	74.9	17.1	8.0	159.1	75.8	16.6	7.6

[1]Butt to 1-inch d.o.b. top.

The average green and dry weight and distribution of all wood in Choctawhatchee sand pines are given in table 6. A pulpwood-size tree in the 6-inch d.b.h. class would have about 61 percent of its green wood weight in the pulpwood portion of the stem, 15 percent in topwood, and 19 percent in branches. Small sawtimber-size trees in the 10-inch d.b.h. class had, on average, 56 percent of their green wood weight in saw-log material, 24 percent in pulpwood, 3 percent in topwood, and 17 percent in branches. The distribution of wood in the tree on a dry-weight basis was about the same as found on a green-weight basis.

Choctawhatchee sand pines growing in the young, open-canopy stands tended to have a larger portion of their green wood weight in branch components. For trees of the same d.b.h. class, trees in older, closed stands contained a 20 to 25 percent greater proportion of wood in the stem portion, compared with trees in open-canopy stands.

The distribution of bark among various tree components is shown in table 7. On the average, a pulpwood-size tree in the 6-inch d.b.h. class had 59 percent of the green bark weight in the pulpwood portion of the main stem, 13 percent in topwood, and 27 percent in branches. The average tree in the 10-inch d.b.h., small sawtimber size class, had 50 percent of its total green bark weight in the saw-log stem, 19 percent in pulpwood, 3 percent in topwood, and 28 percent in branches. On a dry-weight basis, the proportion of bark tended to be less for branches compared with the same components on a green-weight basis, and greater for the butt to 7-inch stem section.

Table 8 shows the distribution of wood and bark in the stem to a 1-inch d.o.b. top. The proportion of stem weight in wood increased and the proportion in bark decreased with increasing tree size. On the average, 87 percent of the green stem weight was wood and 13 percent was bark. For an average pulpwood-size tree in the 8-inch d.o.b. class, the percentage of wood in the green stem was about 90 percent. The distribution of biomass between wood and bark in the stem was about the same for both the green- and dry-weight basis.

Crown Biomass

Average proportion of the green and dry weight of wood, bark, and needles in the crown is given in table 9. For both open- and closed-canopy stands, the proportion of green crown weight in wood increased as tree d.b.h. increased and needle proportion decreased. On the average, 56 percent of crown green weight was wood, 13 percent was bark, and 31 percent was needles.

Mean green and dry crown weights were greater for trees in open-canopy stands than for similar-size trees in closed stands. In stands with an open canopy, the proportion of crown dry weight in needles averaged 19 percent greater than for trees in closed stands.

Dead Branch Material

Field and dry weights of dead branches by d.b.h. class are shown below for stands with a closed canopy:

D.b.h. class	Field weight	Dry weight
	Pounds	
2	1.0	0.8
4	4.2	3.4
6	11.0	9.2
8	20.3	17.0
10	39.8	33.7
Weighted average	12.1	10.1

Weight increased as d.b.h. class increased. The average field moisture content for dead branches equaled 19.8, whereas specific gravity ranged from 0.392 to 0.487 and averaged 0.441. Almost no dead crown material was found in the 7-year-old trees in the two stands with an open overstory canopy.

Table 6.--Average green and dry weight of wood in total tree and distribution of wood in main stem[1] and branches for planted Choctawhatchee sand pine sampled in open- and closed-canopy stands

D.b.h. class (in.)	Total wood weight	Proportion of wood in:					
		Main stem components (d.o.b.)				Total stem	Branches
		Butt-7	7-4	4-2	2-1		
	Lb	Percent					
				OPEN-GREEN			
2	16.8	--	0.1	37.5	19.2	56.8	43.2
4	59.0	--	12.2	45.8	2.2	60.2	39.8
Mean	23.2	--	2.0	38.7	16.6	57.3	42.7
				CLOSED-GREEN			
2	27.1	--	--	70.5	10.8	81.3	18.7
4	101.3	--	25.3	53.0	2.4	81.7	18.3
6	260.9	4.2	60.8	15.2	0.5	80.7	19.3
8	538.5	34.4	44.2	6.1	0.2	84.9	15.0
10	897.6	56.5	23.8	2.6	0.1	83.0	17.0
Mean	293.4	6.4	42.8	30.6	2.2	82.0	18.0
				OPEN-DRY			
2	6.7	--	0.1	37.7	17.8	55.6	44.4
4	23.5	--	12.5	43.7	1.9	58.1	41.9
Mean	9.2	--	2.0	38.6	15.4	56.0	44.0
				CLOSED-DRY			
2	12.9	--	--	72.0	8.9	80.9	19.1
4	47.2	--	27.6	52.2	1.8	81.6	18.4
6	118.7	4.6	61.9	13.9	0.3	80.7	19.3
8	233.4	37.6	42.2	5.3	0.1	85.2	14.8
10	410.6	60.1	21.5	2.1	(2)	83.8	16.2
Mean	132.1	7.6	43.0	29.9	1.6	82.1	17.9

[1]Butt to 1-inch d.o.b. top.

[2]Less then 0.1 percent.

Table 7.--Average green and dry weight of bark in total tree and distribution of bark in main stem[1] and branches for planted Choctawhatchee sand pine sampled in open- and closed-canopy stands

D.b.h. class (in.)	Total bark weight	Proportion of bark in:					
		Main stem component (d.o.b.)				Total stem	Branches
		Butt-7	7-4	4-2	2-1		
	Lb	Percent					
				OPEN-GREEN			
2	4.9	--	0.1	34.7	16.2	51.0	49.0
4	12.5	--	12.0	40.6	1.7	54.3	45.6
Mean	5.5	--	1.9	35.6	14.0	51.5	48.5
				CLOSED-GREEN			
2	6.4	--	--	69.5	7.8	77.4	22.6
4	17.8	--	27.0	45.8	2.0	74.8	25.2
6	39.8	5.0	54.5	12.9	0.6	73.0	27.0
8	69.5	34.4	36.0	5.9	0.3	76.6	23.4
10	106.1	49.9	19.4	3.0	0.2	72.5	27.5
Mean	40.6	6.7	38.6	27.5	1.8	74.6	25.4
				OPEN-DRY			
2	1.7	--	0.2	40.5	14.3	55.0	45.0
4	5.1	--	15.5	47.1	(2)	62.6	37.4
Mean	2.1	--	2.5	41.5	12.1	56.1	43.9
				CLOSED-DRY			
2	2.8	--	--	76.9	3.7	80.6	19.4
4	7.7	--	35.2	43.4	0.4	79.0	21.0
6	17.0	7.7	60.8	9.1	(2)	77.6	22.4
8	27.6	45.3	30.0	3.8	(2)	79.2	20.8
10	44.1	61.3	13.2	1.4	(2)	76.0	24.0
Mean	16.9	10.1	42.0	25.9	0.5	78.5	21.5

[1]Butt to 1-inch d.o.b. top.

[2]Less then 0.1 percent.

Table 8.--Average green and dry weight of stem[1] and proportion of stem in wood and bark for planted Choctawhatchee sand pine sampled in open- and closed-canopy stands

D.b.h. class	Green weight	Stem proportion (green)		Dry weight	Stem proportion (dry)	
		Wood	Bark		Wood	Bark
	Lb	- - - Percent - - -		Lb	- - - Percent - - -	
			OPEN			
2	12.1	79.9	20.1	4.8	79.5	20.5
4	42.2	84.0	16.0	16.8	81.1	18.9
Mean	16.6	80.6	19.4	6.6	79.8	20.2
			CLOSED			
2	27.6	81.6	18.4	13.1	81.3	18.6
4	93.3	85.8	14.2	44.9	85.7	14.3
6	243.1	87.8	12.2	10.9	87.7	12.3
8	511.4	89.5	10.5	221.5	90.0	10.0
10	822.0	90.6	9.4	377.5	91.1	8.9
Mean	274.5	87.0	13.0	123.8	87.1	12.9

[1]Butt to 1-inch d.o.b. top.

Table 9.--Average green and dry weight of crown and proportion of crown in wood, bark, and needles for planted Choctawhatchee sand pine sampled in open- and closed-canopy stands

D.b.h. class (in.)	Crown weight (green)	Crown proportion (green)			Crown weight (dry)	Crown proportion (dry)		
		Branch wood	Branch bark	Needles		Branch wood	Branch bark	Needles
	Lb	Percent			Lb	Percent		
				OPEN				
2	17.0	37.7	11.6	50.7	6.9	38.1	9.7	52.2
4	49.4	47.2	11.5	41.3	19.3	50.8	9.8	39.4
Mean	21.8	39.1	11.6	49.3	8.8	39.9	9.8	50.3
				CLOSED				
2	9.5	48.4	15.1	36.5	4.0	51.3	13.3	35.6
4	34.2	52.6	13.5	33.9	14.6	55.5	11.4	33.1
6	83.3	56.0	12.6	31.4	35.5	58.1	10.5	31.4
8	134.1	59.6	12.1	28.3	55.9	60.1	10.2	29.6
10	237.9	64.1	12.6	23.2	102.3	65.0	10.7	24.2
Mean	83.1	55.5	13.1	31.4	35.3	57.5	11.1	31.4

Wood and Bark Physical Properties

Average specific gravity, moisture content, and green weight per cubic foot are shown in table 10 for the major components of trees growing in open-canopy stands. Similar statistics for trees in closed-canopy stands are given in table 11. Total-tree wood specific gravity averaged 0.443 for trees growing in closed-canopy stands. Wood specific gravity averaged 0.480 in the saw-log stem, 0.461 in the pulpwood portion, and 0.426 in branches. Compared with the specific gravity of the four major southern pines (P. taeda, P. echinata, P. palustris, P. elliottii), Choctawhatchee sand pine specific gravity was, on the average, higher in the main stem but lower in branch wood (Clark and Taras 1976; Taras and Clark 1975, 1977; Taras and Phillips 1978). Bark specific gravity averaged 0.377 for the total tree, 0.398 for the main stem, and 0.294 for branches.

Moisture content of wood averaged 120 percent for the total tree, 103 percent in the saw-log stem, and 114 percent in the pulpwood portion of the main stem compared with branch wood, which had an average moisture content of 128 percent. Compared with Virginia pine (P. virginiana) (Saucier and Boyd 1982), main stem wood moisture content was about 25 percent greater for sand pine. Bark moisture content was higher than wood moisture content for the total tree and branches. Within the main stem, bark moisture content was lower for the saw-log and pulpwood components than for the topwood portions. For the total-tree bark, moisture content averaged 135 percent, 79 percent for the saw-log stem, and 103 percent for the pulpwood portion. Moisture content of the branch bark averaged 181 percent, more than 50 percent higher than branch wood on a dry basis.

The green weight of wood per cubic foot of wood varied only slightly for tree components, and ranged from 60 pounds for branches to 61 pounds for stem wood from a 2- to 1-inch top. The green weight of wood and bark per cubic foot of wood and bark averaged about 58 pounds for branches, and was lowest among the various tree components.

The weight per cubic foot of wood for branches, in relation to other tree components in planted Choctawhatchee sand pine, is opposite to the trend reported for natural Choctawhatchee sand pine (Taras 1980) and natural Virginia pine (Saucier and Boyd 1982). Natural stands tend to have variable spacing which results in poorer pruning and large, older live branches in lower crowns that have denser wood. In contrast, close spacing in planted stands increases natural pruning and results in small branches that have lower wood density. The trend in green bark weight per cubic foot of bark for the components was similar to the other species.

The weight of wood and bark per unit volume of wood is a useful factor for estimating the volume of wood in a tree or its components when weight with bark is known; for example, in weight-scaling truckloads of tree-length logs. For trees in closed-canopy stands, the average green weight of wood and bark per cubic foot of wood was 71 pounds for the total tree, 70 pounds for the stem to a 2-inch d.o.b. top, and 69 pounds for the stem to a 7-inch top. For branch material, the green weight of wood and bark per cubic foot of wood averaged 75 pounds.

Prediction Equations

Tables 12 and 13 contain equations for predicting total-tree and component green and dry weights based on D^2Th, and tables 14 and 15 give equations for estimating cubic volume of wood and bark, with D^2Th also used as the independent variable. Each prediction equation is shown with statistics including the coefficient of determination (R^2) and standard error of estimate ($S_{y.x}$). The corrected sum of squares and mean value of D^2Th and the independent variable are also shown for use in calculating confidence intervals (Appendix, tables 12, 13).

Prediction equations that use tree d.b.h. alone were not developed because the equations might not be applicable to trees in stands on other sites with different diameter:height relationships. However, since local weight and volume

Table 10.--Average wood and bark specific gravity, moisture content, and green weight per cubic foot for planted Choctawhatchee sand pine sampled in open-canopy stands, by tree component

Tree component	Specific gravity	Moisture content	Green weight per cubic foot
		Percent	Pounds
	WOOD		
Total tree	0.408 ± 0.018	149 ± 12	63.4 ± 1.2
Butt to 4-inch d.o.b.	.437 ± .041	141 ± 14	65.6 ± 2.3
4-inch to 2-inch d.o.b.	.409 ± .029	152 ± 16	64.0 ± 1.5
2-inch to 1-inch d.o.b.	.388 ± .028	153 ± 15	63.9 ± 1.5
Main stem	.396 ± .021	150 ± 15	64.1 ± 1.5
Branches	.337 ± .025	142 ± 16	62.9 ± 2.7
	BARK		
Total tree	.337 ± .025	159 ± 25	54.1 ± 3.0
Butt to 4-inch d.o.b.	.444 ± .036	91 ± 13	52.9 ± 2.1
4-inch to 2-inch d.o.b.	.367 ± .029	125 ± 28	51.1 ± 3.8
2-inch to 1-inch d.o.b.	.348 ± .028	119 ± 27	50.8 ± 3.8
Main stem	.354 ± .033	123 ± 28	51.2 ± 3.8
Branches	.394 ± .015	197 ± 20	54.9 ± 4.7
	WOOD AND BARK		
Total tree	.394 ± .015	151 ± 10	61.1 ± 1.5
Butt to 4-inch d.o.b.	.439 ± .032	131 ± 10	63.0 ± 2.1
4-inch to 2-inch d.o.b.	.391 ± .031	154 ± 16	61.8 ± 1.3
2-inch to 1-inch d.o.b.	.371 ± .029	155 ± 15	61.2 ± 1.4
Main stem	.387 ± .017	144 ± 12	62.0 ± 1.6
Branches	.386 ± .016	156 ± 15	60.8 ± 2.7

Mean ± standard deviation.

Table 11.--Average wood and bark specific gravity, moisture content, and green weight per cubic foot for planted Choctawhatchee sand pine sampled in closed-canopy stands, by tree component

Tree component	Specific gravity	Moisture content	Green weight per cubic foot
		Percent	Pounds
	WOOD		
Total tree	0.443 ± 0.028	120 ± 15	60.6 ± 2.4
Butt to 7-inch d.o.b.	.480 ± .048	103 ± 18	60.5 ± 2.3
7-inch to 4-inch d.o.b.	.461 ± .039	114 ± 18	61.2 ± 2.6
4-inch to 2-inch d.o.b.	.415 ± .038	139 ± 25	61.4 ± 3.0
2-inch to 1-inch d.o.b.	.395 ± .036	146 ± 26	61.5 ± 3.0
Main stem	.443 ± .031	121 ± 17	60.9 ± 2.7
Branches	.426 ± .024	128 ± 16	60.4 ± 3.5
	BARK		
Total tree	.337 ± .027	135 ± 20	55.1 ± 3.8
Butt to 7-inch d.o.b.	.453 ± .041	79 ± 25	50.2 ± 4.5
7-inch to 4-inch d.o.b.	.422 ± .034	103 ± 27	53.1 ± 4.9
4-inch to 2-inch d.o.b.	.327 ± .046	198 ± 63	59.2 ± 6.6
2-inch to 1-inch d.o.b.	.311 ± .044	208 ± 66	59.5 ± 6.7
Main stem	.398 ± .030	126 ± 21	55.0 ± 4.7
Branches	.294 ± .027	181 ± 22	51.4 ± 4.9
	WOOD AND BARK		
Total tree	.435 ± .026	121 ± 15	59.6 ± 2.2
Butt to 7-inch d.o.b.	.476 ± .044	99 ± 19	58.8 ± 2.0
7-inch to 4-inch d.o.b.	.455 ± .035	112 ± 18	59.8 ± 2.1
4-inch to 2-inch d.o.b.	.400 ± .035	150 ± 26	61.0 ± 2.7
2-inch to 1-inch d.o.b.	.380 ± .033	157 ± 24	61.3 ± 2.9
Main stem	.436 ± .029	122 ± 18	59.8 ± 2.5
Branches	.396 ± .022	139 ± 14	58.3 ± 3.1

Mean ± standard deviation.

ables are commonly used in timber stand ruising, an appropriate table can be asily developed by the user. First, the ean height of trees in each d.b.h. class f the stand must be determined. These eights are then used to solve the appro- riate weight or volume prediction equa- ion at the midpoint of each d.b.h. class.

For most tree components, with the xception of the crown, the high correla- ion coefficient indicates a close cor- elation between the independent variable D^2Th) and component weights and volumes. he crown weight and volume data were ore variable than stem data, due to reater variation in crown morphology. ample trees were selected from all crown lasses, from suppressed to dominant, and ncluded a wide variation in branch and eedle characteristics, and hence predi- tion equations had a lower coefficient f determination.

Specific equations were not developed o predict weight or volume of the stem ulpwood to various top diameters because f the wide range of pulpwood merchant- bility limits, and because of possible hanges in utilization standards. Instead, separate nonlinear relationship was eveloped to enable the user to obtain stimated stem weight or volume to any ain stem top diameter larger than 1-inch utside bark. Based on a nonlinear model resented by Burkhart (1977), and a modi- ied exponential form presented by Van eusen and others (1981), Clark and homas (1984) developed a model for stimating the proportion of weight or olume to various top diameters of the ain stem for hardwood and pine species n the Southeast:

$$R = e^{(b_1[(d.o.b.\ ^{b_2})(d.b.h.\ ^{b_3})])} \quad (6)$$

here: R = ratio of weight or volume
e = natural base logarithm
d.o.b. = diameter outside bark at specified point
d.b.h. = diameter outside bark at 4.5 feet
b_1, b_2, b_3 = regression coefficients

rediction equations were derived to stimate the ratio of stem weight or volume to a specified diameter to stem weight or volume to a 1-inch top.

Tables 16-18 (Appendix) contain values of these weight and volume ratios for various commonly used combinations of d.b.h. and top d.o.b. limits. Examination of ratio values for green weight of wood and bark of a 10-inch d.b.h. tree reveals that proportions range from about 100 percent of total stem weight contained in the stem to a 1-inch d.o.b. top, to 12 percent for the stem to a 10-inch top, or to a height of 4.5 feet in this example.

Yield Tables

Appendix tables 19-34 were developed from the equations given in tables 12-15 to show total tree and tree component weight and volume by d.b.h. and total height classes. Additional tables may be constructed to show the weight or volume of stem material to various top diameters by applying the ratio values in table 16 to weights and volumes to a 1-inch d.o.b. stem top shown in table 24. For example, to estimate the green weight of wood and bark to an 8-inch d.o.b. top contained in a 10-inch d.b.h. tree 60 feet in height, multiply 933 pounds by 0.518 = 483 pounds. Similar values of weights to a 4- and 7-inch d.o.b. top are shown in tables 26-29.

Similar-size trees may vary in weight and volume because of differences in crown size, stem taper, and weight per cubic foot. Therefore, the equations and tables should be applied only to trees growing in planted, fully stocked stands of Choctawhatchee sand pine that have weights per cubic foot and physical characteristics similar to the trees sampled.

Computation of Confidence Limits

Approximate confidence limits in conventional units of measure can be calculated for lognormal means by using a modification of Cox's formula (Land 1972). By using the statistics of standard errors of the estimate, the sample mean of D^2Th, and the corrected sums of squares for D^2Th of each equation in

$\log_{10}$ form (tables 12-15), confidence intervals in pounds or cubic feet may be obtained by the equation:

$$Y_{U,L} = 10^{\log Y \pm Z \sqrt{S^2_{y \cdot x}\left[\frac{1}{n} + \frac{(x-\bar{x})^2}{\Sigma(x-\bar{x})^2}\right] + \frac{S^4_{y \cdot x}}{2(n+1)}}} \quad (7)$$

where:

$Y_{U,L}$ = upper and lower limits for Y
Y = predicted weight or volume of component from equation (5)
Z = value from the standard normal table appropriate confidence level
$S_{y \cdot x}$ = standard error of estimate for prediction equations
n = number of observations used to develop equation
$\bar{x}$ = sample mean of log x -- (from table of equations)
$(x-\bar{x})^2$ = corrected sums of squares for log x -- (from table of equations)
x = value of independent variable in $\log_{10}$ form

Cox's method of approximation sufficiently estimates actual confidence limits when applied to samples with small variances as occur in the total-tree and stem weight and volume data sets. Thus, equation (7) should be used to approximate confidence limits for the single variable equations presented in this Paper.

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APPENDIX

Conversion factors: English to Metric

Multiply	By	To obtain
Inches	2.540	centimeters
Feet	.3048	meters
Pounds	.4536	kilograms
Cubic feet	.02832	cubic meters
Pounds per cubic foot	16.02	kilograms per cubic meter

All English units of measure in this report can be converted to metric units by multiplying the appropriate conversion factor listed above.

Table 12.--Regression equations for estimating green and dry weight and weight ratios of aboveground biomass of planted Choctawhatchee sand pine trees and tree components in open-canopy stands, with d.b.h. and total height used as independent variables

Weight (Y)	Regression equation[1]	Coefficient of determination (R^2)	Standard error[2] ($S_{y.x}$)
Total tree (including needles):			
Green	$Y = 0.63010(D^2Th)^{0.90101}$	0.97	0.07956
Dry	$Y = 0.26422(D^2Th)^{0.89173}$	.96	.08432
Total tree (excluding needles):			
Green	$Y = 0.24419(D^2Th)^{1.03789}$	.98	.07382
Dry	$Y = 0.09922(D^2Th)^{1.03184}$	.98	.07014
Total tree wood:			
Green	$Y = 0.17028(D^2Th)^{1.06786}$	.98	.07975
Dry	$Y = 0.07293(D^2Th)^{1.05184}$	.98	.07523
Wood and bark in total stem from stump to a 1-inch top d.o.b.:			
Green	$Y = 0.09924(D^2Th)^{1.11259}$	.98	.06878
Dry	$Y = 0.03745(D^2Th)^{1.12328}$	.98	.06588
Wood in total stem from stump to a 1-inch top d.o.b.:			
Green	$Y = 0.07154(D^2Th)^{1.13961}$	.98	.07500
Dry	$Y = 0.02912(D^2Th)^{1.12971}$	.98	.07169
Crown weight (including branch wood, branch bark, and needles):			
Green	$Y = 0.57116(D^2Th)^{0.80488}$	.93	.10526
Dry	$Y = 0.24750(D^2Th)^{0.79025}$	.92	.11541
Needles:			
Green	$Y = 0.49455(D^2Th)^{0.66638}$	.88	.11559
Dry	$Y = 0.22327(D^2Th)^{0.64879}$	.83	.13957
Wood and bark in crown material:			
Green	$Y = 0.14383(D^2Th)^{0.96956}$	.94	.11645
Dry	$Y = 0.05988(D^2Th)^{0.95759}$	.94	.11709
Wood in crown material:			
Green	$Y = 0.09739(D^2Th)^{1.00028}$	.94	.12657
Dry	$Y = 0.04248(D^2Th)^{0.98739}$	.94	.12586

N = 20; Corrected SS for D^2Th = 4.18715; Mean D^2Th = 1.80830.

[1] $Y = b_0(D^2Th)^{b_1}$

where: Y = weight of tree or component in pounds
D = d.b.h. in inches
Th = total height in feet
b_1, b_0 = regression coefficients

[2] Standard error in $\log_{10}$ form.

Table 13.--Regression equations for estimating green and dry weight and weight ratios of aboveground biomass of planted Choctawhatchee sand pine trees and tree components in closed-canopy stands, with d.b.h. and total height used as independent variables

Weight (Y)	Regression equation[1]	Coefficient of determination (R^2)	Standard error[2] ($S_{y.x}$)
Total tree (including needles):			
Green	$Y = 0.28927(D^2Th)^{0.95482}$	0.97	0.08204
Dry	$Y = 0.13420(D^2Th)^{0.94927}$	.97	.07260
Total tree (excluding needles):			
Green	$Y = 0.22798(D^2Th)^{0.97613}$	.98	.06993
Dry	$Y = 0.10806(D^2Th)^{0.96836}$	.98	.06372
Total tree wood:			
Green	$Y = 0.15928(D^2Th)^{1.00545}$	.98	.06903
Dry	$Y = 0.07544(D^2Th)^{0.99909}$	.98	.06343
Wood and bark in total stem from stump to a 1-inch top d.o.b.:			
Green	$Y = 0.14906(D^2Th)^{1.00482}$	.99	.04416
Dry	$Y = 0.07063(D^2Th)^{0.99871}$	.99	.04868
Wood in total stem from stump to a 1-inch top d.o.b.:			
Green	$Y = 0.10571(D^2Th)^{1.03394}$	.99	.04598
Dry	$Y = 0.04846(D^2Th)^{1.03267}$	.99	.05255
Crown weight (including branch wood, branch bark, and needles):			
Green	$Y = 0.15755(D^2Th)^{0.85428}$	.70	.25609
Dry	$Y = 0.06840(D^2Th)^{0.85137}$	.70	.25854
Needles:			
Green	$Y = 0.10836(D^2Th)^{0.73980}$	.64	.25762
Dry	$Y = 0.03832(D^2Th)^{0.76422}$	.66	.25028
Wood and bark in crown material:			
Green	$Y = 0.07629(D^2Th)^{0.90461}$	.72	.26343
Dry	$Y = 0.03617(D^2Th)^{0.89038}$	.70	.27150
Wood in crown material:			
Green	$Y = 0.05260(D^2Th)^{0.92800}$	.72	.26784
Dry	$Y = 0.02700(D^2Th)^{0.90822}$	.69	.27842
Fuelwood (branches, needles and stem > 4-inches d.o.b.):			
Green	$Y = 4.00910(D^2Th)^{0.47660}$	.81	.10621
Dry	$Y = 2.12189(D^2Th)^{0.44547}$	.78	.11009
Fuelwood (branches and stem > 4-inches d.o.b.):			
Green	$Y = 4.39949(D^2Th)^{0.43642}$	.80	.09899
Dry	$Y = 2.49000(D^2Th)^{0.39567}$	.74	.10964

Continued

Table 13.--Regression equations for estimating green and dry weight and weight ratios of aboveground biomass of planted Choctawhatchee sand pine trees and tree components in closed-canopy stands, with d.b.h. and total height used as independent variables--Continued

Weight (Y)	Regression equation[1]	Coefficient of determination (R^2)	Standard error[2] ($S_{y.x}$)
Wood and bark in dead crown material:			
Green	$Y = 0.00342(D^2Th)^{1.10260}$	.76	.28736
Dry	$Y = 0.00279(D^2Th)^{1.10580}$	.76	.28737
	RATIO EQUATIONS[3]		
Wood and bark in stem to any top d.o.b.:			
Green	$Y_r = e^{-0.44474}(d_t^{5.28683})(D^{-4.60481})$		
Dry	$Y_r = e^{-0.42872}(d_t^{5.54740})(D^{-4.89752})$		
Wood in stem to any top d.o.b.:			
Green	$Y_r = e^{-0.46227}(d_t^{5.31122})(D^{-4.62988})$		
Dry	$Y_r = e^{-0.46019}(d_t^{5.52156})(D^{-4.88689})$		

where: Y_r = ratio of stem weight or volume to any d.o.b. top
d_t = specificied stem top d.o.b. in inches
D = tree d.b.h. in inches
e = base of natural log

N = 63; Corrected SS for D^2Th = 13.00063; Mean D^2Th = 3.04845.

[1] $Y = b_0(D^2Th)^{b_1}$

where: Y = weight of tree or component in pounds
D = d.b.h. in inches
Th = total height in feet
b_0, b_1 = regression coefficients

[2] Standard error in $\log_{10}$ form.

[3] Y_r = Weight to any given top d.o.b. (d_t) by using ratio technique. Statistics (R^2) and ($S_{y.x}$) cannot be calculated.

Table 14.--Regression equations for estimating green cubic-foot and volume ratios of aboveground biomass of planted Choctawhatchee sand pine trees and tree components in open-canopy stands, with d.b.h. and total height used as independent variables

Cubic-foot volume (Y)	Regression equation[1]	Coefficient of determination (R^2)	Standard error[2] ($S_{y.x}$)
Total tree:			
Wood α bark	$Y = 0.0092588(D^2Th)^{0.88462}$	0.98	0.06116
Wood	$Y = 0.0063652(D^2Th)^{0.90945}$	.98	.06309
Total stem to a 1-inch top d.o.b.:			
Wood α bark	$Y = 0.0016357(D^2Th)^{1.11081}$	.98	.06943
Wood	$Y = 0.0011852(D^2Th)^{1.12889}$	.98	.07570
Live branch material:			
Wood α bark	$Y = 0.0025967(D^2Th)^{0.94853}$	.94	.11841
Wood	$Y = 0.0015654(D^2Th)^{0.99756}$	.94	.12538

N = 20; Corrected SS for D^2Th = 4.18715; Mean D^2Th = 1.80830.

[1] $Y = b_0(D^2Th)^{b_1}$

where: Y = volume of tree or component in cubic feet
D = d.b.h. in inches
Th = total height in feet
b_0, b_1 = regression coefficients

[2] Standard error in $\log_{10}$ form.

Table 15.--Regression equations for estimating green cubic-foot and volume ratios of planted Choctawhatchee sand pine trees and tree components in closed-canopy stands, with d.b.h. and total height used as independent variables

Cubic-foot volume (Y)	Regression equation[1]	Coefficient of determination (R^2)	Standard error[2] ($S_{y.x}$)
Total tree:			
Wood α bark	$Y = 0.006084(D^2Th)^{0.91556}$	0.98	0.05319
Wood	$Y = 0.003882(D^2Th)^{0.95518}$	.99	.05269
Total stem to a 1-inch top d.o.b.:			
Wood α bark	$Y = 0.002686(D^2Th)^{0.99374}$	.99	.04210
Wood	$Y = 0.001757(D^2Th)^{1.03218}$	.99	.04464
Live branch material:			
Wood α bark	$Y = 0.001542(D^2Th)^{0.88200}$	.70	.26478
Wood	$Y = 0.000969(D^2Th)^{0.91515}$	.70	.27714
Fuelwood (branches and stem > 4-inches d.o.b.):			
Wood α bark	$Y = 0.00000(D^2Th)^{0.41750}$	.78	.10113
Wood	$Y = 0.00000(D^2Th)^{0.43246}$	.79	.10397
Dead branch material:			
Wood α bark	$Y = 0.000100015(D^2Th)^{1.10731}$	.76	.28487
	RATIO EQUATIONS[3]		
Stem volume to any top d.o.b:			
Wood α bark	$Y_r = e^{-0.44534}(d_t^{5.38627})(D^{-4.71582})$		
Wood	$Y_r = e^{-0.48022}(d_t^{5.37425})(D^{-4.72508})$		

where: Y_r = ratio of stem weight or volume to any top d.o.b.
d_t = specificied stem top d.o.b. in inches
D = tree d.b.h. in inches
e = base of natural log

N = 63; Corrected SS for D^2Th = 13.00063; Mean D^2Th = 3.04845.

[1] $Y = b_0(D^2Th)^{b_1}$

where: Y = volume of tree or component in cubic feet
D = d.b.h. in inches
Th = total height in feet
b_1, b_0 = regression coefficients

[2] Standard error in $\log_{10}$ form.

[3] Y_r = Volume to any given top d.o.b. (d_t) by using ratio technique. Statistics (R^2) and ($S_{y.x}$) cannot be calculated.

Table 16.--Ratio of green weight of wood and bark in main stem to a 1-inch top d.o.b. based on d.b.h. class and desired top d.o.b. for planted Choctawhatchee sand pine trees growing in closed-canopy stands in northwest Florida

D.b.h. (in.)	Top diameters outside bark (inches)									
	1	2	3	4	5	6	7	8	9	10
					WOOD AND BARK[1]					
1	0.64099	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	.98189	.48991	.00227	.00000	.00000	.00000	.00000	.00000	.00000	.00000
3	.99718	.89557	.39030	.01349	.00000	.00000	.00000	.00000	.00000	.00000
4	.99925	.97110	.77869	.31829	.02412	.00006	.00000	.00000	.00000	.00000
5	.99973	.98956	.91437	.66385	.26370	.03035	.00037	.00000	.00000	.00000
6	.99988	.99548	.96207	.83782	.56231	.22103	.03304	.00100	.00000	.00000
7	.99994	.99777	.98117	.91667	.75345	.47605	.18697	.03348	.00178	.00002
8	.99997	.99880	.98977	.95404	.85807	.66943	.40388	.15935	.03260	.00254
9	.99998	.99930	.99404	.97302	.91486	.79190	.59032	.34377	.13665	.03099
10	.99999	.99957	.99633	.98330	.94669	.86621	.72290	.51824	.29369	.11782
11	.99999	.99972	.99763	.98920	.96530	.91155	.81123	.65455	.45386	.25187
12	.99999	.99981	.99841	.99275	.97662	.93985	.86923	.75284	.58909	.39706
					WOOD[2]					
1	.62985	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
2	.98163	.47894	.00176	.00000	.00000	.00000	.00000	.00000	.00000	.00000
3	.99718	.89388	.38041	.01163	.00000	.00000	.00000	.00000	.00000	.00000
4	.99926	.97090	.77539	.30962	.02160	.00004	.00000	.00000	.00000	.00000
5	.99974	.98957	.91363	.65947	.25618	.02769	.00029	.00000	.00000	.00000
6	.99989	.99551	.96197	.83639	.55741	.21455	.03049	.00083	.00000	.00000
7	.99994	.99780	.98122	.91633	.75138	.47105	.18140	.03114	.00153	.00001
8	.99997	.99882	.98985	.95406	.85742	.66689	.39904	.15457	.03049	.00223
9	.99998	.99931	.99411	.97314	.91479	.79092	.58749	.33925	.13255	.02912
10	.99999	.99958	.99638	.98344	.94684	.86601	.72164	.51529	.28956	.11431
11	.99999	.99973	.99767	.98933	.96551	.91170	.81088	.65308	.45093	.24815
12	.99999	.99982	.99845	.99286	.97683	.94013	.86936	.75237	.58750	.39425

[1] $Y_r = e^{-0.44474}(d_t^{5.28683})(D^{-4.60481})$

[2] $Y_r = e^{-0.46227}(d_t^{5.31122})(D^{-4.63988})$

where: Y_r = ratio of stem weight or volume to any top d.o.b.
d_t = specificied stem top d.o.b. in inches
D = tree d.b.h. in inches
e = base of natural log

Table 17.--Ratio of dry weight of wood and bark in main stem to a 1-inch top d.o.b. based on d.b.h. class and desired top d.o.b. for planted Choctawhatchee sand pine trees growing in closed-canopy stands in northwest Florida

D.b.h. (in.)	Top diameters outside bark (inches)									
	1	2	3	4	5	6	7	8	9	10
					WOOD AND BARK[1]					
1	0.65134	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	.98572	.51034	.00170	.00000	.00000	.00000	.00000	.00000	.00000	.00000
3	.99803	.91179	.41666	.01332	.00000	.00000	.00000	.00000	.00000	.00000
4	.99952	.97768	.80737	.34803	.02627	.00005	.00000	.00000	.00000	.00000
5	.99984	.99246	.93078	.70198	.29518	.03492	.00037	.00000	.00000	.00000
6	.99993	.99691	.97105	.86512	.60677	.25318	.03954	.00114	.00000	.00000
7	.99997	.99854	.98629	.93417	.79070	.52432	.21906	.04138	.00220	.00002
8	.99998	.99924	.99285	.96521	.88505	.71482	.45406	.19089	.04146	.00331
9	.99999	.99957	.99598	.98031	.93372	.82814	.64182	.39449	.16733	.04046
10	.99999	.99975	.99760	.98820	.95989	.89355	.76744	.57395	.34399	.14742
11	.99999	.99984	.99849	.99258	.97466	.93186	.84707	.70601	.51216	.30107
12	.99999	.99990	.99902	.99515	.98338	.95496	.89728	.79666	.64601	.45662
					WOOD[2]					
1	.63116	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
2	.98457	.48945	.00123	.00000	.00000	.00000	.00000	.00000	.00000	.00000
3	.99786	.90619	.39686	.01084	.00000	.00000	.00000	.00000	.00000	.00000
4	.99947	.97614	.79727	.32979	.02230	.00003	.00000	.00000	.00000	.00000
5	.99982	.99192	.92669	.68881	.27858	.03027	.00028	.00000	.00000	.00000
6	.99993	.99668	.96925	.85819	.59195	.23815	.03470	.00089	.00000	.00000
7	.99997	.99843	.98540	.93053	.78125	.50889	.20550	.03661	.00177	.00001
8	.99998	.99918	.99237	.96320	.87938	.70345	.43870	.17866	.03687	.00273
9	.99999	.99954	.99570	.97914	.93026	.82052	.62917	.37963	.15630	.03613
10	.99999	.99973	.99743	.98748	.95772	.88851	.75814	.56058	.32987	.13748
11	.99999	.99983	.99839	.99212	.97325	.92849	.84047	.69540	.49852	.28781
12	.99999	.99989	.99894	.99484	.98243	.95266	.89262	.78864	.63445	.44305

$^{1}Y_r = e^{-0.42872}(d_t^{5.54740})(D^{-4.89752})$

$^{2}Y_r = e^{-0.46019}(d_t^{5.52156})(D^{-4.88689})$

where: Y_r = ratio of stem weight or volume to any top d.o.b.
d_t = specificied stem top d.o.b. in inches
D = tree d.b.h. in inches
e = base of natural log

Table 18.--Ratio of cubic volume of wood and bark contained in main stem to a 1-inch top d.o.b. based on d.b.h. class and desired top d.o.b. for planted Choctawhatchee sand pine trees growing in closed-canopy stands in northwest Florida

D.b.h. (in.)	Top diameters outside bark (inches)									
	1	2	3	4	5	6	7	8	9	10
					WOOD AND BARK[1]					
1	0.64061	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	.98320	.49224	.00185	.00000	.00000	.00000	.00000	.00000	.00000	.00000
3	.99750	.90056	.39447	.01252	.00000	.00000	.00000	.00000	.00000	.00000
4	.99936	.97339	.78698	.32365	.02346	.00004	.00000	.00000	.00000	.00000
5	.99977	.99063	.91977	.67445	.26978	.03026	.00033	.00000	.00000	.00000
6	.99990	.99602	.96522	.84646	.57435	.22753	.03350	.00094	.00000	.00000
7	.99995	.99808	.98304	.92258	.76488	.48888	.19365	.03438	.00174	.00001
8	.99998	.99897	.99093	.95798	.86693	.68300	.41703	.16606	.03384	.00255
9	.99999	.99941	.99478	.97567	.92133	.80351	.60540	.35692	.14328	.03248
10	.99999	.99964	.99682	.98512	.95137	.87537	.73687	.53428	.30661	.12429
11	.99999	.99977	.99797	.99048	.96869	.91859	.82300	.67038	.47039	.26440
12	.99999	.99985	.99865	.99368	.97912	.94522	.87876	.76697	.60632	.41373
					WOOD[2]					
1	.61865	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
2	.98201	.47090	.00129	.00000	.00000	.00000	.00000	.00000	.00000	.00000
3	.99733	.89506	.37536	.01007	.00000	.00000	.00000	.00000	.00000	.00000
4	.99931	.97193	.77750	.30695	.01987	.00003	.00000	.00000	.00000	.00000
5	.99976	.99013	.91605	.66265	.25533	.02633	.00024	.00000	.00000	.00000
6	.99990	.99582	.96363	.84040	.56167	.21509	.02964	.00074	.00000	.00000
7	.99995	.99798	.98228	.91950	.75697	.47627	.18297	.03077	.00142	.00001
8	.99997	.99892	.99053	.95633	.86230	.67389	.40506	.15688	.03055	.00214
9	.99999	.99938	.99456	.97473	.91859	.79754	.59571	.34587	.13541	.02953
10	.99999	.99963	.99669	.98456	.94969	.87152	.72989	.52448	.29661	.11754
11	.99999	.99976	.99789	.99013	.96763	.91608	.81816	.66276	.46086	.25547
12	.99999	.99984	.99860	.99345	.97843	.94355	.87543	.76134	.59838	.40469

$$^{1}Y_r = e^{-0.44534}(d_t^{5.38627})(D^{-4.71582})$$

$$^{2}Y_r = e^{-0.48022}(d_t^{5.37425})(D^{-4.72508})$$

where: Y_r = ratio of stem weight or volume to any top d.o.b.
d_t = specificied stem top d.o.b. in inches
D = tree d.b.h. in inches
e = base of natural log

Table 19.--Predicted weight of total tree (wood, bark, and needles) aboveground for planted Choctawhatchee sand pine trees growing in open-canopy stands in northwest Florida[1]

d.b.h. (in.)	Total-tree height[2] (feet)						
	10	12	14	16	18	20	22
	Pounds						
	GREEN[3]						
.5	1.4	1.7	1.9	2.2			
.0	5.0	5.9	6.8	7.7	8.5		
.5	10.4	12.3	14.1	15.9	17.7	19.5	
.0	17.5	20.6	23.7	26.7	29.7	32.7	
.5		30.8	35.4	39.9	44.4	48.8	53.2
.0		42.8	49.2	55.5	61.7	67.8	73.9
.5			64.9	73.2	81.4	89.6	97.6
.0			82.6	93.2	103.6	113.9	124.1
.5				115.2	128.1	140.8	153.5
.0				139.3	154.9	170.3	185.6
.5						202.2	220.3
.0						236.5	257.7
	DRY[4]						
.5	0.6	0.7	0.8	0.9			
.0	2.1	2.4	2.8	3.1	3.5		
.5	4.2	5.0	5.7	6.5	7.2	7.9	
.0	7.1	8.3	9.6	10.8	12.0	13.2	
.5		12.4	14.2	16.0	17.8	19.6	21.3
.0		17.2	19.7	22.2	24.7	27.1	29.5
.5			26.0	29.2	32.5	35.7	38.9
.0			32.9	37.1	41.2	45.3	49.3
.5				45.8	50.9	55.9	60.8
.0				55.3	61.4	67.4	73.4
.5						79.9	87.0
.0						93.3	101.6

[1]Blocked-in area indicates range of data.

[2]Includes 0.1-foot stump allowance.

[3]$Y = 0.63010(D^2Th)^{0.90101}$

[4]$Y = 0.26424(D^2Th)^{0.89173}$

where: Y = weight of total tree or component in pounds
D = d.b.h. in inches
Th = total height in feet

Table 20.--Predicted weight of total tree (wood, bark, and needles) aboveground for planted Choctawhatchee sand pine trees growing in closed-canopy stands in northwest Florida[1]

D.b.h. (in.)	Total-tree height[2] (feet)						
	10	20	30	40	50	60	70
	Pounds						
	GREEN[3]						
1	3	5	7				
2	10	19	28	37	46		
3	21	41	61	80	99	118	
4	37	71	105	138	171	204	
5	56	109	161	212	262	312	361
6		155	228	300	371	442	512
7		208	306	403	498	593	687
8			395	519	643	765	886
9				650	805	958	1110
10				795	984	1172	1357
11					1181	1405	1628
12					1394	1659	1923
	DRY[4]						
1	1	2	3				
2	4	9	13	17	21		
3	10	19	27	36	44	53	
4	17	32	47	62	76	91	
5	25	49	72	95	117	139	161
6		69	102	134	165	196	227
7		93	136	179	221	263	305
8			176	231	285	339	392
9				289	357	424	491
10				352	436	518	600
11					522	621	718
12					616	732	847

[1]Blocked-in area indicates range of data.

[2]Includes 0.1-foot stump allowance.

[3]$Y = 0.28927(D^2Th)^{0.95482}$

[4]$Y = 0.13420(D^2Th)^{0.94927}$

where: Y = weight of total tree or component in pounds
D = d.b.h. in inches
Th = total height in feet

Table 21.--Predicted weight of total tree (wood and bark) aboveground for planted Choctawhatchee sand pine trees growing in open-canopy stands in northwest Florida[1]

D.b.h. (in.)	Total-tree height[2] (feet)						
	10	12	14	16	18	20	22
	Pounds						
	GREEN[3]						
0.5	0.6	0.8	0.9	1.0			
1.0	2.7	3.2	3.8	4.3			
1.5	6.2	7.5	8.8	10.1	11.4	12.7	
2.0	11.2	13.6	15.9	18.3	20.7	23.1	
2.5		21.6	25.3	29.1	32.9	36.6	40.5
3.0		31.5	37.0	42.4	48.0	53.5	59.1
3.5			50.9	58.5	66.1	73.7	81.3
4.0			67.1	77.1	87.2	97.2	107.3
4.5				98.5	111.3	124.1	137.1
5.0				122.6	138.5	154.5	170.6
5.5						188.3	207.9
6.0						225.6	249.0
	DRY[4]						
0.5	0.3	0.3	0.4	0.4			
1.0	1.1	1.3	1.5	1.7	2.0		
1.5	2.5	3.0	3.5	4.0	4.5	5.0	
2.0	4.5	5.4	6.3	7.2	8.2	9.1	
2.5		8.5	10.0	11.5	13.0	14.5	16.0
3.0		12.4	14.6	16.7	18.9	21.1	23.2
3.5			20.0	23.0	26.0	29.0	32.0
4.0			26.4	30.3	34.2	38.2	42.1
4.5				38.6	43.6	48.6	53.7
5.0				48.0	54.2	60.5	66.7
5.5						73.6	81.2
6.0						88.1	97.2

[1]Blocked-in area indicates range of data.

[2]Includes 0.1-foot stump allowance.

[3]$Y = 0.24419(D^2Th)^{1.03789}$

[4]$Y = 0.09922(D^2Th)^{1.03184}$

where: Y = weight of total tree or component in pounds
D = d.b.h. in inches
Th = total height in feet

Table 22.--Predicted weight of total tree (wood and bark) aboveground for planted Choctawhatchee sand pine trees growing in closed-canopy stands in northwest Florida[1]

D.b.h. (in.)	Total-tree height[2] (feet)						
	10	20	30	40	50	60	70
	Pounds						
	GREEN[3]						
1	2	4	6				
2	8	16	24	32	40		
3	18	36	54	71	89	106	
4	32	64	94	125	155	186	
5	50	98	146	193	240	287	334
6		140	208	276	343	410	477
7		190	282	373	464	554	644
8			365	484	602	719	836
9				609	757	905	1052
10				748	930	1111	1292
11					1120	1339	1556
12					1328	1586	1844
	DRY[4]						
1	1	2	3				
2	4	8	11	15	18		
3	8	17	24	32	40	48	
4	15	29	43	56	70	83	
5	23	44	66	87	108	129	149
6		63	94	124	153	183	213
7		85	126	167	207	247	286
8			163	216	268	320	371
9				271	337	401	466
10				332	413	492	572
11					496	592	688
12					587	701	814

[1]Blocked-in area indicates range of data.

[2]Includes 0.1-foot stump allowance.

[3]$Y = 0.22798(D^2Th)^{0.97613}$

[4]$Y = 0.15928(D^2Th)^{0.96836}$

where: Y = weight of total tree or component in pounds
D = d.b.h. in inches
Th = total height in feet

Table 23.--Predicted weight of total-tree wood aboveground for planted Choctawhatchee sand pine trees growing in closed-canopy stands in northwest Florida[1]

D.b.h. (in.)	Total-tree height[2] (feet)						
	10	20	30	40	50	60	70
	Pounds						
	GREEN[3]						
1	2	3	5				
2	7	13	20	26	33		
3	15	29	44	59	74	89	
4	26	53	79	106	132	159	
5	41	82	124	165	207	249	290
6		119	179	239	299	359	419
7		162	244	325	407	489	571
8			319	426	533	640	747
9				539	675	811	947
10				667	834	1002	1170
11					1010	1214	1417
12					1204	1446	1688
	DRY[4]						
1	1	2	2				
2	3	6	9	12	15		
3	7	14	20	27	34	41	
4	12	24	36	48	60	72	
5	19	38	56	75	94	112	131
6		54	81	108	135	162	189
7		73	110	147	184	220	257
8			144	192	240	288	335
9				243	303	364	424
10				300	374	449	524
11					453	543	634
12					539	646	754

[1]Blocked-in area indicates range of data.

[2]Includes 0.1-foot stump allowance.

[3]$Y = 0.15928(D^2Th)^{1.00545}$

[4]$Y = 0.07544(D^2Th)^{0.99909}$

where: Y = weight of total tree or component in pounds
D = d.b.h. in inches
Th = total height in feet

Table 24.--Predicted weight of total-stem wood and bark for planted Choctawhatchee sand pine trees growing in closed-canopy stands in northwest Florida[1]

D.b.h. (in.)	Total-tree height[2] (feet)						
	10	20	30	40	50	60	70
	Pounds						
	GREEN[3]						
1	2	3	5				
2	6	12	18	24	31		
3	14	28	41	55	69	83	
4	24	49	74	98	123	148	
5	38	77	115	154	193	232	270
6		111	166	222	278	334	390
7		151	227	303	379	455	532
8			297	396	496	596	695
9				502	628	755	881
10				621	777	933	1089
11					940	1130	1319
12					1120	1345	1571
	DRY[4]						
1	1	1	2				
2	3	6	8	11	14		
3	6	13	19	25	32	38	
4	11	22	34	45	56	67	
5	18	35	53	70	87	105	122
6		50	76	101	126	151	176
7		69	103	137	171	206	240
8			134	179	224	268	313
9				226	283	340	396
10				280	349	419	489
11					423	507	591
12					503	603	704

[1]Blocked-in area indicates range of data.

[2]Includes 0.1-foot stump allowance.

[3]$Y = 0.14906(D^2Th)^{1.00482}$

[4]$Y = 0.07063(D^2Th)^{0.99871}$

where: Y = weight of total tree or component in pounds
D = d.b.h. in inches
Th = total height in feet

Table 25.--Predicted weight of total-stem wood (bark excluded) for planted Choctawhatchee sand pine trees growing in closed-canopy stands in northwest Florida[1]

D.b.h. (in.)	Total-tree height[2] (feet)						
	10	20	30	40	50	60	70
	Pounds						
GREEN[3]							
1	1	2	4				
2	5	10	15	20	25		
3	11	23	35	46	59	71	
4	20	41	63	84	106	128	
5	32	65	99	134	168	203	238
6		95	145	195	245	296	347
7		131	199	268	338	408	478
8			262	353	445	537	630
9				451	568	685	804
10				560	706	852	999
11					859	1038	1217
12					1029	1242	1457
DRY[4]							
1	1	1	2				
2	2	4	7	9	12		
3	5	10	16	21	27	32	
4	9	19	28	38	48	58	
5	15	30	45	61	76	92	108
6		43	66	89	111	135	158
7		59	90	122	153	185	217
8			119	160	202	244	286
9				204	257	311	364
10				254	320	386	453
11					390	470	552
12					466	563	660

[1]Blocked-in area indicates range of data.

[2]Includes 0.1-foot stump allowance.

[3]$Y = 0.10571(D^2Th)^{1.03394}$

[4]$Y = 0.04846(D^2Th)^{1.03267}$

where: Y = weight of total tree or component in pounds
D = d.b.h. in inches
Th = total height in feet

Table 26.--Predicted weight of wood and bark in stem to 4-inch top d.o.b. for planted Choctawhatchee sand pine trees growing in closed-canopy stands in northwest Florida[1]

D.b.h. (in.)	Total-tree height[2] (feet)						
	10	20	30	40	50	60	70
	Pounds						
	GREEN[3]						
4	8	16	23	31	39	47	
5	25	51	77	102	128	154	180
6		93	139	186	233	280	327
7		138	208	278	348	417	487
8			283	378	473	568	663
9				489	611	734	857
10				610	764	917	1071
11					930	1117	1305
12					1112	1336	1559
	DRY[4]						
4	4	8	12	16	19	23	
5	12	25	37	49	61	74	86
6		44	65	87	109	131	152
7		64	96	128	160	192	224
8			130	173	216	259	302
9				222	277	333	388
10				276	345	414	483
11					419	503	587
12					500	600	700

[1]Blocked-in area indicates range of data.

[2]Includes 0.1-foot stump allowance.

[3] $Y = 0.14906(D^2Th)^{1.00482}$

$R = e^{-0.44(d_t^{5.29})(D^{-4.60})}$

$Y_r = R(Y)$

[4] $Y = 0.07063(D^2Th)^{0.99871}$

$R = e^{-0.43(d_t^{5.55})(D^{-4.90})}$

$Y_r = R(Y)$

where: Y = total stem weight in pounds
d_t = specified stem top d.o.b. in inches
D = d.b.h. in inches
Th = total height in feet
R = ratio of weight to 4-inch top to total stem weight
Y_r = estimated stem weight to 4-inch top d.o.b.
e = base of natural log

Table 27.--Predicted weight of wood excluding bark in stem to 4-inch top d.o.b. for planted Choctawhatchee sand pine trees growing in closed-canopy stands in northwest Florida[1]

D.b.h. (in.)	Total-tree height[2] (feet)						
	10	20	30	40	50	60	70
	Pounds						
	GREEN[3]						
4	6	13	19	26	33	40	
5	21	43	65	88	111	134	157
6		80	121	163	205	248	291
7		120	182	246	309	373	438
8			250	337	424	512	601
9				439	552	667	782
10				551	694	838	983
11					850	1027	1204
12					1022	1233	1447
	DRY[4]						
4	3	6	9	13	16	19	
5	10	20	31	42	53	64	75
6		37	56	76	96	115	135
7		55	84	113	143	172	202
8			115	154	194	235	275
9				200	252	304	357
10				251	316	382	447
11					387	467	547
12					464	560	657

[1]Blocked-in area indicates range of data.

[2]Includes 0.1-foot stump allowance.

[3] $Y = 0.10571(D^2Th)^{1.03394}$

$R = e^{-0.46(d_t^{5.31})(D^{-4.64})}$

$Y_r = R(Y)$

[4] $Y = 0.04846(D^2Th)^{1.03267}$

$R = e^{-0.46(d_t^{5.52})(D^{-4.89})}$

$Y_r = R(Y)$

where: Y = total stem weight in pounds
d_t = specified stem top d.o.b. in inches
D = d.b.h. in inches
Th = total height in feet
R = ratio of weight to 4-inch top to total stem weight
Y_r = estimated stem weight to 4-inch top d.o.b.
e = base of natural log

Table 28.--Predicted weight of wood and bark in stem to 7-inch top d.o.b. for planted Choctawhatchee sand pine trees growing in closed-canopy stands in northwest Florida[1]

D.b.h. (in.)	Total-tree height[2] (feet)				
	30	40	50	60	70
	Pounds				
	GREEN[3]				
7	42	57	71	85	99
8	120	160	200	241	281
9		296	371	446	520
10		449	561	674	787
11			763	916	1070
12			974	1169	1365
	DRY[4]				
7	23	30	38	45	53
8	61	81	102	122	142
9		145	182	218	254
10		215	268	322	375
11			358	429	501
12			451	541	631

[1]Blocked-in area indicates range of data.

[2]Includes 0.1-foot stump allowance.

[3] $Y = 0.14906(D^2Th)^{1.00482}$

$R = e^{-0.44}(d_t^{5.29})(D^{-4.60})$

$Y_r = R(Y)$

[4] $Y = 0.07063(D^2Th)^{0.99871}$

$R = e^{-0.43}(d_t^{5.55})(D^{-4.90})$

$Y_r = R(Y)$

where: Y = total stem weight in pounds
d_t = specified stem top d.o.b. in inches
D = d.b.h. in inches
Th = total height in feet
R = ratio of weight to 7-inch top to total stem weight
Y_r = estimated stem weight to 7-inch top d.o.b.
e = base of natural log

Table 29.--Predicted weight of wood excluding bark in stem to 7-inch top d.o.b. for planted Choctawhatchee sand pine trees growing in closed-canopy stands in northwest Florida[1]

D.b.h. (in.)	Total-tree height[2] (feet)				
	30	40	50	60	70
	Pounds				
	GREEN[3]				
7	36	49	61	74	87
8	105	141	178	214	251
9		265	333	403	472
10		404	509	615	721
11			697	841	987
12			894	1080	1267
	DRY[4]				
7	19	25	31	38	45
8	52	70	89	107	125
9		129	162	196	229
10		193	243	293	343
11			328	395	464
12			416	503	589

[1]Blocked-in area indicates range of data.

[2]Includes 0.1-foot stump allowance.

[3] $Y = 0.10571(D^2Th)^{1.03394}$

$R = e^{-0.46}(d_t^{5.31})(D^{-4.64})$

$Y_r = R(Y)$

[4] $Y = 0.04846(D^2Th)^{1.03267}$

$R = e^{-0.46}(d_t^{5.52})(D^{-4.89})$

$Y_r = R(Y)$

where: Y = total stem weight in pounds
d_t = specified stem top d.o.b. in inches
D = d.b.h. in inches
Th = total height in feet
R = ratio of weight to 7-inch top to total stem weight
Y_r = estimated stem weight to 7-inch top d.o.b.
e = base of natural log

Table 30.--Predicted volume of total tree (wood and bark) aboveground for planted Choctawhatchee sand pine trees growing in open-canopy stands in northwest Florida[1]

D.b.h. (in.)	Total-tree height[2] (feet)						
	10	12	14	16	18	20	22
	Cubic feet						
WOOD AND BARK[3]							
0.5	0.02	0.02	0.03	0.03			
1.0	.07	.08	.10	.11	0.12		
1.5	.15	.17	.20	.22	.24	0.27	
2.0	.24	.28	.33	.37	.41	.45	
2.5		.42	.48	.54	.60	.66	0.72
3.0		.58	.67	.75	.83	.92	1.00
3.5			.88	.99	1.10	1.20	1.31
4.0			1.11	1.25	1.39	1.52	1.66
4.5				1.54	1.71	1.88	2.04
5.0				1.86	2.06	2.26	2.46
5.5						2.68	2.91
6.0						3.12	3.39
WOOD[4]							
0.5	0.01	0.02	0.02	0.02			
1.0	.05	.06	.07	.08	.09		
1.5	.11	.13	.15	.17	.18	0.20	
2.0	.18	.22	.25	.28	.31	.34	
2.5		.32	.37	.42	.47	.51	0.56
3.0		.45	.52	.58	.65	.72	.78
3.5			.68	.77	.86	.95	1.03
4.0			.87	.99	1.10	1.21	1.32
4.5				1.22	1.36	1.50	1.63
5.0				1.48	1.65	1.81	1.98
5.5						2.16	2.35
6.0						2.53	2.75

[1]Blocked-in area indicates range of data.

[2]Includes 0.1-foot stump allowance.

[3]$Y = 0.0092588(D^2Th)^{0.88462}$

[4]$Y = 0.0063652(D^2Th)^{0.90945}$

where: Y = volume of total tree or component in cubic feet
D = d.b.h. in inches
Th = total height in feet

Table 31.--Predicted volume of total tree (wood and bark) aboveground for planted Choctawhatchee sand pine trees growing in closed-canopy stands in northwest Florida[1]

D.b.h. (in.)	Total-tree height[2] (feet)						
	10	20	30	40	50	60	70
	Cubic feet						
	WOOD AND BARK[3]						
1	0.05	0.09	0.14				
2	.18	.34	.49	.63	.78		
3	.37	.71	1.02	1.33	1.63	1.93	
4	.63	1.20	1.73	2.26	2.77	3.27	
5	.95	1.80	2.61	3.40	4.17	4.92	5.67
6		2.51	3.64	4.74	5.82	6.87	7.91
7		3.33	4.83	6.29	7.71	9.11	10.50
8			6.17	8.03	9.85	11.64	13.40
9				9.96	12.22	14.44	16.63
10				12.08	14.82	17.51	20.17
11					17.65	20.85	24.01
12					20.69	24.45	28.16
	WOOD[4]						
1	0.04	0.07	0.10				
2	.13	.26	.38	.49	.61		
3	.29	.55	.82	1.07	1.33	1.58	
4	.49	.96	1.41	1.86	2.30	2.74	
5	.76	1.47	2.16	2.85	3.53	4.20	4.86
6		2.08	3.07	4.04	4.99	5.94	6.89
7		2.79	4.12	5.42	6.70	7.98	9.25
8			5.31	6.99	8.65	10.30	11.93
9				8.76	10.84	12.90	14.94
10				10.71	13.25	15.77	18.28
11					15.90	18.92	21.93
12					18.77	22.35	25.89

[1]Blocked-in area indicates range of data.

[2]Includes 0.1-foot stump allowance.

[3]$Y = 0.006084(D^2Th)^{0.91556}$

[4]$Y = 0.003882(D^2Th)^{0.95518}$

where: Y = volume of total tree or component in cubic feet
D = d.b.h. in inches
Th = total height in feet

Table 32.--Predicted volume of total stem (wood and bark) for planted Choctawhatchee sand pine trees growing in closed-canopy stands in northwest Florida[1]

D.b.h. (in.)	Total-tree height[2] (feet)						
	10	20	30	40	50	60	70
	Cubic feet						
	WOOD AND BARK[3]						
1	0.03	0.05	0.08				
2	.10	.21	.31	0.42	0.52		
3	.24	.47	.70	.93	1.16	1.39	
4	.42	.83	1.24	1.65	2.06	2.47	
5	.65	1.29	1.93	2.57	3.21	3.85	4.49
6		1.86	2.78	3.70	4.61	5.53	6.44
7		2.52	3.77	5.02	6.27	7.51	8.76
8			4.92	6.55	8.17	9.79	11.42
9				8.27	10.33	12.38	14.43
10				10.20	12.73	15.26	17.79
11					15.39	18.44	21.50
12					18.29	21.93	25.56
	WOOD[4]						
1	0.02	0.04	0.06				
2	.08	.16	.25	0.33	0.42		
3	.18	.37	.57	.76	.96	1.16	
4	.33	.68	1.03	1.38	1.74	2.10	
5	.52	1.07	1.63	2.19	2.76	3.34	3.91
6		1.56	2.38	3.20	4.03	4.86	5.70
7		2.15	3.27	4.40	5.53	6.68	7.83
8			4.30	5.79	7.29	8.80	10.32
9				7.39	9.30	11.22	13.16
10				9.18	11.56	13.95	16.36
11					14.07	16.98	19.91
12					16.84	20.35	23.83

[1]Blocked-in area indicates range of data.

[2]Includes 0.1-foot stump allowance.

[3]$Y = 0.002686(D^2Th)^{0.99374}$

[4]$Y = 0.001757(D^2Th)^{1.03218}$

where: Y = volume of total tree or component in cubic feet
D = d.b.h. in inches
Th = total height in feet

Table 33.--Predicted volume of stem (wood and bark) to 4-inch top d.o.b. for planted Choctawhatchee sand pine trees growing in closed-canopy stands in northwest Florida[1]

D.b.h. (in.)	Total-tree height[2] (feet)						
	10	20	30	40	50	60	70
	Cubic feet						
	WOOD AND BARK[3]						
4	0.13	0.27	0.40	0.53	0.67	0.80	
5	.44	.87	1.30	1.73	2.17	2.60	3.03
6		1.57	2.35	3.13	3.90	4.68	5.46
7		2.33	3.48	4.63	5.78	6.93	8.08
8			4.71	6.27	7.83	9.38	10.94
9				8.07	10.08	12.08	14.08
10				10.05	12.54	15.03	17.52
11					15.24	18.27	21.29
12					18.18	21.79	25.39
	WOOD[4]						
4	0.10	0.21	0.32	0.42	0.54	0.65	
5	.35	.71	1.08	1.45	1.83	2.21	2.59
6		1.31	2.00	2.69	3.38	4.08	4.79
7		1.98	3.00	4.04	5.09	6.14	7.20
8			4.12	5.54	6.97	8.42	9.87
9				7.20	9.06	10.94	12.83
10				9.04	11.38	13.73	16.10
11					13.93	16.82	19.72
12					16.73	20.19	23.67

[1]Blocked-in area indicates range of data.

[2]Includes 0.1-foot stump allowance.

[3] $Y = 0.002686(D^2Th)^{0.99374}$

$R = e^{-0.44(d_t^{5.39})(D^{-4.72})}$

$Y_r = R(Y)$

[4] $Y = 0.001757(D^2Th)^{1.03218}$

$R = e^{-0.48(dt^{5.37})(D^{-4.73})}$

$Y_r = R(Y)$

where: Y = total stem volume in cubic feet
d_t = specified stem top d.o.b. in inches
D = d.b.h. in inches
Th = total volume in cubic feet
R = ratio of volume to 4-inch top to total stem volume
Y_r = estimated stem volume to 4-inch top d.o.b.
e = base of natural log

Table 34.--Predicted volume of stem (wood and bark) to 7-inch top d.o.b. for planted Choctawhatchee sand pine trees growing in closed-canopy stands in northwest Florida[1]

D.b.h. (in.)	Total-tree height[2] (feet)				
	30	40	50	60	70
	- - - - - Cubic feet - - - - -				
	WOOD AND BARK[3]				
7	0.73	0.97	1.21	1.45	1.70
8	2.05	2.73	3.41	4.08	4.76
9		5.01	6.25	7.49	8.73
10		7.52	9.38	11.25	13.11
11			12.66	15.18	17.69
12			16.08	19.27	22.46
	WOOD[4]				
7	0.60	0.80	1.01	1.22	1.43
8	1.74	2.35	2.95	3.56	4.18
9		4.40	5.54	6.69	7.84
10		6.70	8.44	10.18	11.94
11			11.51	13.90	16.29
12			14.74	17.79	20.86

[1]Blocked-in area indicates range of data.

[2]Includes 0.1-foot stump allowance.

[3] $Y = 0.002686(D^2Th)^{0.99374}$

$R = e^{-0.44(d_t^{5.39})(D^{-4.72})}$

$Y_r = R(Y)$

[4] $Y = 0.001757(D^2Th)^{1.03218}$

$R = e^{-0.48(d_t^{5.37})(D^{-4.73})}$

$Y_r = R(Y)$

where: Y = total stem volume in cubic feet
d_t = specified stem top d.o.b. in inches
D = d.b.h. in inches
Th = total volume in cubic feet
R = ratio of volume to 7-inch top to total stem volume
Y_r = estimated stem volume to 7-inch top d.o.b.
e = base of natural log

McNab, W. Henry; Outcalt, Kenneth W.; Brendemuehl, Raymond H.
Weight and volume of plantation-grown Choctawhatchee sand pine.
Res. Pap. SE-252. Asheville, NC: U.S. Department of Agriculture,
Forest Service, Southeastern Forest Experiment Station; 1985. 44 pp.

The aboveground green weight of the total tree and its major components, the main stem and crown, were determined in eight stands of planted Choctawhatchee sand pine ranging in age from 7 to 27 years. Eighty-three trees, ranging in d.b.h. from 0.7 to 11.1 inches from 11 to 59 feet in total height, were sampled. After testing for significant differences, data were stratified to provide two sets of composite equations: one for the six stands with a closed canopy, i.e., ages 12 to 27 years, and one for the young stands where crown closure had not yet occurred. Equations for predicting individual tree green and dry weights and cubic volumes of wood, and of wood and bark, were developed for the main stem and crown of each canopy class. Ratio equations were developed to allow estimation of weights and volumes to specified top stem diameter. Tables for estimating green and dry weight and cubic volume are given for the total tree and its major components, based on d.b.h. and total height.

KEYWORDS: Pinus clausa var. immuginata, biomass, prediction equations.

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KEYWORDS: Pinus clausa var. immuginata, biomass, prediction equations.

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Weight, Volume, and Physical Properties of Major Hardwood Species in the Southern Appalachian Mountains

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April 1986

Southeastern Forest Experiment Station
P.O. Box 2680
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ABSTRACT

The weight, volume, and physical properties of trees 1 to 20 inches d.b.h. were determined for basswood, blackgum (upland), red maple, yellow-poplar, white oak, sweet birch, black locust, hickory, black oak, chestnut oak, northern red oak, scarlet oak, and white oak in the Southern Appalachian Mountains. Hard hardwoods, soft hardwoods, and individual species equations are presented for predicting green and dry weight and green volume of the total tree above-stump and its components by using d.b.h. and total height, d.b.h. and height to a 4-inch top, d.b.h. and saw-log merchantable height, and d.b.h. alone. Average specific gravity, moisture content, and weight per cubic foot of wood, bark, and wood and bark combined are presented for each species by tree size class and component. Bark percentage is also presented for each species by tree size class and component.

Keywords: Biomass, equations, specific gravity, moisture content, bark percentage, weight per cubic foot.

The hardwood forests of the Southern Appalachian Mountains can contribute significantly to supplies of solid wood, fiber, and energy wood through improved utilization and forest management. Few data, however, exist on the weight, volume, and physical properties of the total tree and its components for hardwood species of this region.

To meet this need, the USDA Forest Service collected tree weight and volume data for the important hardwood species growing in this region. These data were used to develop equations for estimating the weight and volume of individual trees and tree components. The specific gravity, moisture content, and bark content of the trees sampled were also determined.

This Paper presents green volume and green and dry weight equations for the total tree and tree components of 13 species--basswood (Tilia americana L.), upland blackgum (Nyssa sylvatica Marsh.), red maple (Acer rubrum L.), yellow-poplar (Liriodendron tulipifera L.), white ash (Fraxinus americana L.), sweet birch (Betula lenta L.), black locust (Robinia pseudoacacia L.), hickory species (Carya spp.), black oak (Quercus velutina Lam.), chestnut oak (Q. prinus L.), northern red oak (Q. rubra L.), scarlet oak (Q. coccinea Muenchh.), and white oak (Q. alba L.). Equations were developed from tree data collected in the Southern Appalachian Mountains of western North Carolina and northeastern Georgia. These species account for more than 85 percent of the commercial hardwood volume in this region. Equations were also developed for the combined hard hardwoods, combined soft hardwoods, and all 13 species.

Equations are given for estimating the weight and volume of wood and bark and wood only in the total tree, total stem, and the saw-log component of the stem. Ratio equations are also included for estimating saw-log stem weight or volume to any specified top diameter outside bark (d.o.b.). Wood and bark specific gravity, moisture content, bark content, and green weight per cubic foot are presented for the total tree and its components, by species and tree size classes.

Procedure

Field

Trees were selected from fully stocked, uneven-aged hardwood stands on the Chattahoochee National Forest in Georgia and the Pisgah and Nantahala National Forests in North Carolina. A stratified random sample of three to five trees per 2-inch d.b.h. class was selected at each sample location. Sample trees generally ranged from 5 to 20 or 22 inches d.b.h. Means and ranges in age and tree dimensions measured are shown in table 1 for each species and species group sampled. Stump height averaged 0.5 foot for trees 5.0 to 10.9 inches d.b.h. and 0.6 foot for trees $\geq$ 11.0 inches d.b.h. Form class of the sawtimber-size trees ($\geq$ 11.0 inches d.b.h.) ranged from 64 to 91 and averaged 80 for the soft hardwoods, and ranged from 61 to 90 and averaged 78 for the hard hardwoods.

Each tree was felled and measured for d.o.b. at 4-foot intervals up the stem. Total height, and height to the saw-log top, 9-, 4-, and 2-inch d.o.b., and base of full live crown were also recorded. Cross-sectional disks of wood and bark were removed from the stem and branches of sample trees for laboratory determination of specific gravity, moisture content, bark percentage, energy value, and nutrient concentration. In all trees $\geq$ 5.0 inches d.b.h. except sawtimber-quality trees ($\geq$ 11.0 inches d.b.h. with a minimum of one 16-foot grade 3 log), disks were cut at the butt, d.b.h., and quarter-points to the 4-inch d.o.b. top and at the 2-inch top. In sawtimber trees, disks were removed at the butt, at each saw-log bucking point, and at the stem location where d.o.b. measured 9, 4, and 2 inches.

The branches of each tree were cut from the stem and weighed in four size categories: extra large ($\geq$ 4.0 inches d.o.b.), large (2.0 to 3.9 inches d.o.b.), medium (0.6 to 1.9 inches d.o.b.), and small ($\leq$ 0.5 inch d.o.b.). Three cross-sectional disks were cut from randomly selected branches in each size category for analysis in the laboratory.

The stem of each tree was weighed by components (saw logs, pulpwood, and topwood) and the branches of each tree were weighted by size category.

Laboratory

Specific gravity was computed on green volume and ovendry weight. Moisture content was computed on ovendry weight after samples were dried to a constant weight at 215 °F. Percentage of bark was determined from disks and based on the green weight of sample disks. Moisture content, specific gravity, and percentage of bark in stem, branches, and total tree were calculated by weighting disk values in proportion to the volume of the component they represented. Weighted values for moisture content were used to convert component green weights to ovendry weight.

By using species diameter inside bark (d.i.b.) prediction equations, developed from d.o.b. and d.i.b. stem disk measurements, and the d.o.b. and height measurements taken at 4-foot intervals up the stem of each tree, the volume of wood in the stem to the saw log 9-inch, 4-inch, 2-inch, and tip were calculated by Smalian's formula. Green weight per cubic foot of stem bark and of branch wood and bark were calculated from weighted values for specific gravity and moisture content with the equation:

$$\text{Green weight per cubic foot} = \left[1 + \frac{MC}{100}\right] \cdot (SG) \cdot (C) \qquad (1)$$

where: MC = weighted moisture content in percent

SG = weighted specific gravity

C = 62.4 pounds (weight of water per cubic foot)

Cubic-foot volume of stem bark and branch wood and bark were computed by dividing green component weight by its green weight per cubic foot. Cubic-foot volume of stem wood and bark combined was computed by adding the volume of bark to the volume of wood.

Analysis

Regression equations were developed to predict green and dry weight and green volume of wood and bark in the total tree above stump, stem from butt to tip, and saw-log stem. Independent variables were: diameter at breast height (D), total height (Th), saw-log merchantable height (Mh), and height to a 4-inch d.o.b. top (H4).

A logarithmic transformation (base 10) was used to obtain a relatively homogeneous variance, which is assumed in regression analysis. Two equations were developed for the d.b.h., d.b.h. and total height, and d.b.h. and height to 4-inch top--one for trees < 11.0 inches d.b.h. and one for trees $\geq$ 11.0 inches d.b.h. The 11-inch point was not the optimum point to shift from one equation to the other for all species or tree components, but it was the most desirable from a practical standpoint. Hardwood trees < 11 inches in diameter are classified as sapling or poletimber, and trees $\geq$ 11 inches are classified as sawtimber. The procedure outlined in Draper and Smith (1981) for fitting two linear equations with a known point of intersection was used to develop the following equations:

$$\log Y_p = a + b \log X + E \quad (2)$$

$$\log Y_s = a + b \log (11^2 H) + c \log (D^2/11^2) + E \quad (3)$$

where: Y_p = predicted component weight or volume for trees < 11.0 inches d.b.h.

Y_s = predicted component weight or volume for trees $\geq$ 11.0 inches d.b.h.

X = D^2, D^2Th or D^2H4

H = Th or H4

D = d.b.h.

E = experimental error

a,b,c = regression coefficients

The following model was used for developing regression equations based on d.b.h. and saw-log merchantable height:

$$\log Y = a + b \log X_1 + c \log X_2 + E \quad (4)$$

where: Y = predicted component weight or volume

$X_1 = D^2$

$X_2 = Mh$

E = experimental error

a,b,c = regression coefficients

When logarithmic estimates are converted back to original units, they are biased downward because the antilogarithm of an estimated mean gives the geometric rather then the arithmetic mean (Cunia 1964). To adjust for this bias, a correction factor was computed and applied to each model by using Baskerville's (1972) procedure. The final equations, including correction factors, were:

$$Y = 10^{a + b \log (D^2) + c \log (Mh) + (S^2_{y \cdot x} \log_e 10)/2} \quad (5)$$

$$Y_p = 10^{a + b \log (D^2H) + (S^2_{y \cdot x} \log_e 10)/2} \quad (6)$$

$$Y_s = 10^{a + b \log (11^2H) + c \log (D^2/11^2) + (S^2_{y \cdot x} \log_e 10)/2} \quad (7)$$

Equations (5), (6), and (7) can be simplified to:

$$Y = a' (D^2)^b (Mh)^c \quad (8)$$

$$Y_p = a' (D^2H)^b \quad (9)$$

$$Y_s = a'' (D^2)^b (H)^c \quad (10)$$

where: $a' = 10^{a + (S^2_{y \cdot x} \log_e 10)/2}$

$a'' = a' (11^2)^b - c$

$S^2_{y \cdot x}$ = error mean square from regression analysis

Comparison of average deviations (actual minus predicted) by d.b.h. classes and the sums of the squared deviations for the single log-log equation and segmented log-log equation showed that segmented log-log equations (9) and (10) gave the best results for the d.b.h., d.b.h. and total height, and d.b.h. and height to 4-inch top independent variable combinations (Clark and others 1985). Equations (9) and (10) are more complex than a single equation, but the improved accuracy justified their use.

The following exponential ratio equation was used to estimate the proportion of predicted total-stem weight or volume to a specified top d.o.b.:

$$Y_R = e^a (d^b D^c) \quad (11)$$

where: Y_R = ratio of stem weight or volume to top d.o.b. to predicted total stem

d = specified stem top diameter in inches

D = tree diameter at breast height in inches

a,b,c = regression coefficients

e = base of natural log = 2.71828

The exponential ratio model shown below was developed to estimate a ratio for expanding saw-log stem weight or volume to any d.o.b. top above the saw-log top.

$$Y_R = e^a \left[(Mh)^b \left(\left(1-\left(\frac{d}{.78D} \right)^2\right)^2\right)^c \right] \quad (12)$$

where: Y_R = ratio of stem weight or volume to top d.o.b. to saw-log stem

Mh = saw-log merchantable height in feet

d = specified top diameter in inches

D = tree diameter at breast height in inches

.78 = constant based on average form class

a,b,c = regression coefficients

e = base of natural log

Results

Physical Properties of Sample Trees

The average specific gravity of wood and bark by tree component is shown in table 2 for individual species, soft hardwoods, hard hardwoods, and all trees combined. The average total-tree wood specific gravity of the soft hardwood species was 0.439 for poletimber (5.0 to 10.9 inches) and 0.440 for sawtimber ($\geq$ 11.0 inches d.b.h.) compared with hard hardwood species, which averaged 0.598 for poletimber and 0.604 for sawtimber. Basswood had the lowest average total-tree wood specific gravity and blackgum the highest for the soft hardwoods group. In the hard hardwoods group, sweet birch had the lowest average total-tree wood specific gravity and hickory had the highest.

The average moisture content of wood and bark by tree component and size class is shown in table 3 for the species and species groups sampled. Total-tree wood moisture content for the soft hardwoods averaged 105 percent for poletimber and 99 percent for sawtimber compared with hard hardwoods, which averaged 62 percent for poletimber and 67 percent for sawtimber. In the soft hardwoods group, basswood had the highest average total-tree moisture content compared with red maple, which had the lowest. In the hard hardwoods group, white oak had the lowest total-tree wood moisture content and northern red oak had the highest.

Table 4 shows the average proportion of bark in the tree, based on green weight of wood and bark, by tree component and size class for the species sampled.

Basswood had the highest bark percentage of the soft hardwoods and chestnut oak had the highest for the hard hardwoods. The percentage of stem weight in bark increased as stem d.o.b. decreased. Thus, poletimber trees generally had a higher proportion of the green weight in bark than did sawtimber trees, and branches had the highest proportion of green weight in bark.

The average green weight per cubic foot of wood, bark, and wood and bark combined, by tree component, for poletimber and sawtimber are shown in table 5. Because of the soft hardwood and hard hardwood species grouping, the average range of green weight for cubic foot of wood for the two groups is similar--49 to 67 pounds for the soft hardwoods and 52 to 67 pounds for the hard hardwoods. This is caused by the relatively high moisture content and specific gravity of blackgum in the soft hardwoods group and the low moisture content of white ash in the hard hardwoods group. The average green weight per cubic foot of wood for the soft hardwood species was 56 pounds for poletimber and 54 pounds for sawtimber compared with 62 pounds for pole and sawtimber hard hardwoods.

The average green weight of wood and bark per cubic foot of wood by tree component for poletimber and sawtimber-size trees is shown in table 6. The weight of wood and bark per cubic-foot volume of wood is a useful factor for estimating the volume of wood in a tree or its components when weight of wood and bark is known or for estimating green weight of wood and bark when volume of wood is known. The green weight of wood and bark per cubic foot of wood for the total tree averaged 68 pounds for poletimber and 65 pounds for sawtimber soft hardwoods compared with 75 pounds for poletimber and sawtimber hard hardwoods.

The average green weight of wood and bark per cubic foot of wood was highest for branches and decreased with increasing stem diameter (table 6).

Prediction Equations

A series of equations was developed to predict total-tree and tree component weight and volume for each species, the soft hardwood and hard hardwood groups, and all species combined. Equations were developed for predicting the green and dry weight of wood and bark combined and wood alone in the above-stump total tree. Stem equations were developed for estimating the green and dry weight of wood and bark combined, and wood alone for the total stem. Volume equations were also developed for wood and bark combined and wood alone in the above-stump total tree and total stem.

Since tree height is measured to different top limits by various organizations, equations were developed by using diameter (D) alone and in combination with total height (Th), height to 4-inch top (H4), and merchantable height (Mh) as independent variables. Equation (9) was used to estimate the weight and volume of the total tree and stem for trees 5.0 to 10.9 inches d.b.h., and equation (10) was used for trees $\geq$ 11.0 inches d.b.h. when D alone, D and Th, or D and H4 were the independent variables.

Equation (8) was used to estimate weight and volume of the total tree and saw-log merchantable stem for trees $\geq$ 11.0 inches d.b.h. when D and Mh were the independent variables. Equations based on D and Mh were developed only for species sampled sufficiently in the sawtimber diameter classes. Equations were developed for the soft hardwoods, hard hardwoods, and all species, and for yellow-poplar, white oak, hickory, black oak, chestnut oak, northern red oak, scarlet oak, and white oak.

Equation (11) was used to estimate the proportion of total-stem weight or volume in the stem to any d.o.b. top when stem weight or volume was estimated with D, D and Th, or D and H4 as the independent variables. Equation (12) was used to estimate a ratio for expanding estimated saw-log merchantable-stem weight or volume to any d.o.b. top above the saw-log top when D and Mh were the independent variables.

Equations that use D with Th or D with H4 fit the existing total-tree and total-stem weight and volume data well, based on the criteria of mean square error and absolute deviation of observed from predicted. Equations that use D and Mh fit existing saw-log merchantable-stem weight and volume data well. When average tree height and stem taper are similar to those of our sample trees, the equations with D alone will result in good estimates of the tree weight and volume. When average tree height by d.b.h. class are different from the sample trees, however, the equations that include a height variable should be applied directly or used to develop local weight-volume tables based on D alone.

Regression coefficients for estimating weight and volume are listed below, by independent variable and table number:

Independent variable	Weight	Volume
D alone	tables 7, 8	tables 9, 10
D and Th	tables 11, 12	tables 13, 14
D and H4	tables 15, 16	tables 17, 18
D and Mh	tables 19, 20	tables 21, 22

In addition to the regression coefficients, tables 7 through 22 contain the coefficients of determination and standard error (log_{10}) for each equation.

Regression coefficients for estimating the proportion of the total-stem weight and volume in the stem to a specified d.o.b. top are given in tables 23 and 24. Table 23 contains coefficients for estimating ratios for stem green and dry weight of wood and bark combined and wood only, and table 24 contains the coefficients for stem volume of wood and bark combined and wood alone. Equation coefficients for expanding estimated saw-log merchantable-stem weight and volume are shown in tables 25 and 26, respectively.

How to Use Prediction Equations

The following examples illustrate how to use the equations in tables 7 through 26 to estimate the weight or volume of the total tree and its components.

This tabulation presents the tree data needed to estimate weight and volume when d.b.h. and Th are measured and equations (9) and (10) are used:

Example of trees < 11.0 inches d.b.h.

D = 10.0 inches

Th = 70 feet

Example of trees $\geq$ 11.0 inches

D = 14.0 inches

Th = 90 feet

To estimate total-stem wood and bark green weight (Y_{STEMWB}) of a soft hardwood with these dimensions, the following equations would be selected from table 12 and solved as follows:

Trees < 11.0 inches d.b.h.--use equation (9)

$$Y_{STEMWB} = a' (D^2Th)^b$$

$$= 0.19934 ((10^2) (70))^{0.94973}$$

$$= 0.19934 (7000)^{0.94973}$$

$$= 0.19934 (4,485.44)$$

$$Y_{STEMWB} = 894 \text{ pounds}$$

Trees $\geq$ 11 inches d.b.h.--use equation (10)

$$Y_{STEMWB} = a'' (D^2)^b (Th)^c$$

$$= 0.16133 (14^2)^{0.99384} (90)^{0.94973}$$

$$= 0.16133 (196)^{0.99384} (90)^{0.94973}$$

$$= 0.16133 (189.73) (71.78)$$

$$Y_{STEMWB} = 2,197 \text{ pounds}$$

The same mathematical procedure shown above would be used to solve equations (9) or (10) for any of the tree component equations in tables 7 through 22.

To estimate the proportion of total-stem green weight of wood and bark in the stem of a 10-inch d.b.h. tree to a 4-inch d.o.b. top (Y_R), the following soft hardwood ratio regression coefficients would be selected from table 23 and solved by using equation (11) as shown below. The same equation is used for all size trees.

$$Y_R = e^a (d)^b (D)^c$$

$$= 2.71828 \left[-2.21340 (4)^{3.69663} (10)^{-4.00734}\right]$$

$$= 2.71828 \left[-2.21340 (168.11) (0.000098)\right]$$

$$= 2.71828^{-0.03647}$$

$$Y_R = 0.964$$

Stem weight to 4-inch top = $(Y_{STEMWB})\ (Y_R)$

$= 894\ (0.964)$

Stem weight to 4-inch top = 862 pounds

The procedure shown above can be used to estimate the proportion of total stem in the stem to any d.o.b. top by substituting for d in equation (11).

The following tabulation shows the tree data needed to estimate weights and volumes when d.b.h. and Mh are measured and equation (8) is used.

D = 14.0 inches d.b.h.

Mh = 2.0 logs

To use equation (8), Mh must be in feet, thus:

Mh = 33.1 feet = (2.0 logs) (16.3 ft/log) + (0.5 ft for stump)

To estimate the green weight of wood and bark in the saw-log merchantable stem (Y_{SAWWB}) of a soft hardwood tree, by using equation (8) the following coefficients would be selected from table 20 and solved as follows:

$$Y_{SAWWB} = a' (D^2)^b (Mh)^c$$

$$= 0.55968\ (14^2)^{0.97608}\ (33.1)^{0.76439}$$

$$= 0.55968\ (172.75)\ (14.51)$$

$$Y_{SAWWB} = 1{,}403 \text{ pounds}$$

The same mathematical procedure shown above would be used to solve equation (8) for any sawtimber tree component equation in tables 19 through 22.

To estimate a ratio (Y_R) for expanding estimated saw-log merchantable-stem green weight of wood and bark of the previous tree to weight to a 4-inch d.o.b. top, the following soft hardwood ratio equation would be selected from table 25 and solved by using equation (12) as shown below:

$$Y_R = e^a \left[(Mh)^b \left(\left(1 - \left(\frac{d}{.780} \right)^2 \right)^2 \right)^c \right]$$

$$= 2.71828^{20.03667} \left[(33.1)^{-1.15011} \left(\left(1 - \left(\frac{4}{.78(14)} \right)^2 \right)^2 \right)^{0.30738} \right]$$

$$= 2.71828^{20.03667(0.01787)(0.91524)}$$

$$= 2.71828^{0.32764}$$

$$Y_R = 1.388$$

Stem weight to 4-inch top = (Y_{SAWWB}) (Y_R)

= 1,403 (1.388)

Stem weight to 4-inch top = 1,947 pounds

The tree components predicted by using the equations provided can be used to calculate additional tree components. For example, to estimate the weight or volume of the crown (branches and topwood) subtract estimated weight of the stem to a specified d.o.b. top from total-tree weight of wood and bark. The weight or volume of bark alone can also be estimated by subtracting component weight or volume of wood from wood and bark.

Similar-size trees may vary in weight and volume because of differences in crown size, stem taper, and weight per cubic foot. Therefore, these equations should be applied only to trees growing in natural, fully stocked stands with tree dimensions and weight per cubic foot similar to the tree sampled.

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TABLES

Table 1.--Mean and range of tree age and measurements, by species and tree size class

Tree size class (inches)	Sample trees	Age		D.b.h.		Total height		Height to 4-inch d.o.b. top		Height to saw-log merchantable top		D.o.b. at saw-log merchantable top	
		Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
	Number			- - - Inches - - -		- - - - - - - - - - - - - - - Feet - - - - - - - - - - - - - - -						- - - Inches - - -	
						SOFT HARDWOODS							
5.0-10.9	60	55	16-146	8.1	5.1-10.7	67	34-102	38	12-73	--	--	--	--
>11.0	68	77	50-198	15.8	11.0-25.6	98	58-147	77	39-129	50	16-99	10.5	7.8-18.0
All trees	128	67	16-198	12.2	5.1-25.6	84	34-147	58	12-129	50	16-99	10.5	7.8-18.0
						BASSWOOD							
5.0-10.9	9	60	46-75	8.0	5.6-10.5	72	63-82	41	23-59	--	--	--	--
>11.0	9	76	52-100	14.1	11.8-16.5	91	80-106	69	57-82	27	16-37	12.0	9.4-15.4
All trees	18	68	46-100	11.1	5.6-16.5	82	63-106	55	23-82	27	16-37	12.0	9.4-15.4
						BLACKGUM							
5.0-10.9	9	97	80-146	8.0	5.7-10.0	49	34-58	27	14-41	--	--	--	--
>11.0	9	140	72-198	14.6	12.0-17.8	73	58-100	54	39-78	42	30-67	9.3	9.0-10.9
All trees	18	119	72-198	11.3	5.7-17.8	61	34-100	40	14-78	42	30-67	9.3	9.0-10.9
						RED MAPLE							
5.0-10.9	18	59	42-73	8.0	5.1-10.7	65	47-86	36	12-60	--	--	--	--
>11.0	12	65	50-89	14.2	12.0-16.8	83	63-104	58	43-80	28	9-50	11.0	8.0-14.9
All trees	30	61	42-89	10.5	5.1-16.8	72	47-104	45	12-80	28	9-50	11.0	8.0-14.9
						YELLOW-POPLAR							
5.0-10.9	24	36	16-75	8.1	5.6-10.7	73	51-102	42	17-73	--	--	--	--
>11.0	38	66	50-76	17.0	11.0-25.6	111	84-147	90	59-129	64	28-99	10.2	7.8-18.2
All trees	62	54	16-76	13.6	5.6-25.6	97	51-147	71	17-129	64	28-99	10.2	7.8-18.2
						HARD HARDWOODS							
5.0-10.9	143	60	19-114	8.1	5.0-10.9	65	36-92	39	9-67	--	--	--	--
>11.0	204	91	45-175	16.3	11.0-24.7	90	61-120	70	40-104	42	16-78	11.6	8.1-19.0
All trees	347	78	19-175	12.9	5.0-24.7	80	36-120	57	9-104	42	16-78	11.6	8.1-19.0
						WHITE ASH							
5.0-10.9	27	57	25-85	8.0	5.0-10.3	67	44-84	42	15-67	--	--	--	--
>11.0	25	87	54-147	15.1	11.0-21.8	91	73-119	71	52-103	35	16-73	12.4	9.0-19.0
All trees	52	72	25-147	11.4	5.0-21.8	79	44-119	56	15-103	35	16-73	12.2	9.0-19.0

Continued

Table 1.--Mean and range of tree age and measurements, by species and tree size class--Continued

Tree size class (inches)	Sample trees	Age		D.b.h.		Total height		Height to 4-inch d.o.b. top		Height to saw-log merchantable top	
		Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
	Number			Inches		Feet					
					SWEET BIRCH						
5.0-10.9	9	47	32-73	8.1	5.8-10.5	62	53-74	33	20-46	--	--
>11.0	12	74	51-105	15.0	11.9-18.5	79	67-98	56	46-73	23	16-39
All trees	21	62	32-105	12.1	5.8-18.5	72	53-98	46	20-73	23	16-39
					BLACK LOCUST						
5.0-10.9	9	24	19-39	8.1	5.6-10.2	57	36-68	34	22-48	--	--
>11.0	9	50	45-79	13.8	11.6-16.4	81	65-99	61	45-86	35	25-45
All trees	18	37	19-79	11.0	5.6-16.4	69	36-99	48	22-86	35	25-45
					HICKORY						
5.0-10.9	20	75	26-114	8.1	5.1-10.9	67	42-92	40	12-65	--	--
>11.0	34	115	74-175	16.3	11.6-23.1	93	72-120	74	53-104	44	17-74
All trees	54	99	26-175	13.3	5.1-23.1	84	42-120	62	12-104	44	17-74
					BLACK OAK						
5.0-10.9	9	72	41-109	8.3	6.2-10.5	63	44-80	37	16-55	--	--
>11.0	18	106	68-170	17.0	11.8-21.8	84	74-97	64	48-77	38	26-57
All trees	26	94	41-170	13.8	6.2-21.8	77	44-97	55	16-77	38	26-57
					CHESTNUT OAK						
5.0-10.9	18	80	46-107	8.2	5.6-10.9	62	47-85	38	18-57	--	--
>11.0	32	104	68-151	16.4	11.5-22.3	87	61-115	70	46-94	45	28-66
All trees	50	95	46-151	13.4	5.6-22.3	78	47-115	58	18-94	45	28-66
					NORTHERN RED OAK						
5.0-10.9	33	48	35-55	8.3	5.9-10.9	70	53-86	43	18-65	--	--
>11.0	38	74	50-114	17.1	11.1-24.7	96	67-118	74	50-98	50	25-78
All trees	71	62	35-114	13.0	5.9-24.7	84	53-118	60	18-98	50	25-78
					SCARLET OAK						
5.0-10.9	9	65	47-81	8.0	5.7-10.2	56	44-72	32	13-53	--	--
>11.0	18	87	52-124	17.0	11.7-22.2	87	63-105	66	40-87	44	24-54
All trees	27	80	47-124	14.0	5.7-22.2	76	44-105	55	13-87	44	24-54

Table 1.--Mean and range of tree age and measurements, by species and tree size class--Continued

Tree size class (inches)	Sample trees	Age		D.b.h.		Total height		Height to 4-inch d.o.b. top		Height to saw-log merchantable top		D.o.b. at saw-log merchantable top	
		Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
	Number			- - - Inches - - -		- - - - - - - - - - - - - - - Feet - - - - - - - - - - - - - - -						- - - Inches - - -	
WHITE OAK													
5.0-10.9	9	70	54-86	7.9	5.1-10.3	61	38-84	36	9-60	--	--	--	--
>11.0	19	91	62-130	16.7	11.6-21.7	94	72-110	72	53-85	46	34-64	11.9	8.4-18.0
All trees	28	84	54-130	13.9	5.1-21.7	84	38-110	60	9-85	46	34-64	11.9	8.4-18.0
ALL SPECIES													
5.0-10.9	203	59	16-146	8.1	5.0-10.9	66	34-102	39	9-73	--	--	--	--
>11.0	272	87	22-198	16.2	11.0-25.6	92	58-147	71	39-129	44	16-99	11.3	7.8-19.0
All trees	475	75	16-198	12.7	5.0-25.6	81	34-147	57	9-129	44	16-99	11.3	7.8-19.0

Table 2.--Average specific gravity of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Southern Appalachian Mountains

Tree size class (inches)	Average and standard deviation						
		Stem					
	Total tree	Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	Branches
SOFT HARDWOODS							
Wood							
5.0-10.9	0.439 ± 0.073	--	--	0.442 ± 0.075	0.436 ± 0.070	0.440 ± 0.074	0.440 ± 0.070
≥11.0	0.440 ± 0.062	0.440 ± 0.064	0.451 ± 0.061	0.440 ± 0.063	0.456 ± 0.063	0.440 ± 0.063	0.447 ± 0.063
Bark							
5.0-10.9	0.441 ± 0.094	--	--	0.457 ± 0.101	0.437 ± 0.104	0.462 ± 0.094	0.379 ± 0.121
≥11.0	0.400 ± 0.088	0.404 ± 0.099	0.425 ± 0.086	0.407 ± 0.097	0.413 ± 0.087	0.408 ± 0.095	0.371 ± 0.092
Wood and Bark							
5.0-10.9	0.440 ± 0.072	--	--	0.443 ± 0.073	0.436 ± 0.068	0.444 ± 0.073	0.421 ± 0.073
≥11.0	0.434 ± 0.061	0.434 ± 0.063	0.446 ± 0.058	0.434 ± 0.062	0.448 ± 0.059	0.435 ± 0.063	0.426 ± 0.062
BASSWOOD							
Wood							
5.0-10.9	0.353 ± 0.022	--	--	0.359 ± 0.024	0.345 ± 0.017	0.357 ± 0.024	0.324 ± 0.008
≥11.0	0.364 ± 0.033	0.371 ± 0.040	0.362 ± 0.022	0.368 ± 0.035	0.354 ± 0.030	0.368 ± 0.034	0.339 ± 0.031
Bark							
5.0-10.9	0.418 ± 0.023	--	--	0.421 ± 0.023	0.421 ± 0.026	0.423 ± 0.023	0.406 ± 0.022
≥11.0	0.411 ± 0.015	0.422 ± 0.018	0.413 ± 0.017	0.419 ± 0.017	0.407 ± 0.025	0.418 ± 0.017	0.396 ± 0.018
Wood and Bark							
5.0-10.9	0.369 ± 0.017	--	--	0.370 ± 0.021	0.366 ± 0.013	0.370 ± 0.020	0.354 ± 0.010
≥11.0	0.374 ± 0.027	0.378 ± 0.034	0.372 ± 0.019	0.376 ± 0.029	0.369 ± 0.026	0.376 ± 0.029	0.359 ± 0.024
BLACKGUM							
Wood							
5.0-10.9	0.524 ± 0.027	--	--	0.528 ± 0.034	0.518 ± 0.028	0.526 ± 0.032	0.521 ± 0.015
≥11.0	0.509 ± 0.054	0.514 ± 0.056	0.497 ± 0.054	0.511 ± 0.056	0.523 ± 0.057	0.511 ± 0.056	0.500 ± 0.049
Bark							
5.0-10.9	0.471 ± 0.029	--	--	0.455 ± 0.039	0.465 ± 0.038	0.457 ± 0.037	0.494 ± 0.031
≥11.0	0.448 ± 0.048	0.437 ± 0.074	0.435 ± 0.083	0.435 ± 0.076	0.464 ± 0.054	0.436 ± 0.074	0.460 ± 0.024

Continued

Table 2.--Average specific gravity of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Southern Appalachian Mountains--Continued

Tree size class (inches)	Average and standard deviation						
		Stem					
	Total tree	Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	Branches
				Wood and Bark			
5.0-10.9	0.513 ± 0.023	--	--	0.512 ± 0.026	0.503 ± 0.024	0.516 ± 0.027	0.511 ± 0.015
≥11.0	0.502 ± 0.041	0.504 ± 0.041	0.486 ± 0.038	0.500 ± 0.041	0.508 ± 0.035	0.505 ± 0.046	0.488 ± 0.036
				RED MAPLE			
				Wood			
5.0-10.9	0.507 ± 0.022	--	--	0.512 ± 0.025	0.496 ± 0.024	0.509 ± 0.024	0.497 ± 0.026
≥11.0	0.515 ± 0.032	0.516 ± 0.036	0.518 ± 0.032	0.516 ± 0.034	0.517 ± 0.031	0.516 ± 0.034	0.515 ± 0.031
				Bark			
5.0-10.9	0.559 ± 0.038	--	--	0.594 ± 0.036	0.566 ± 0.045	0.590 ± 0.035	0.482 ± 0.051
≥11.0	0.544 ± 0.033	0.572 ± 0.039	0.573 ± 0.043	0.572 ± 0.039	0.555 ± 0.026	0.571 ± 0.038	0.504 ± 0.039
				Wood and Bark			
5.0-10.9	0.516 ± 0.020	--	--	0.523 ± 0.023	0.508 ± 0.020	0.520 ± 0.022	0.491 ± 0.024
≥11.0	0.520 ± 0.026	0.522 ± 0.032	0.526 ± 0.025	0.522 ± 0.031	0.524 ± 0.024	0.523 ± 0.030	0.511 ± 0.027
				YELLOW-POPLAR			
				Wood			
5.0-10.9	0.389 ± 0.028	--	--	0.388 ± 0.028	0.393 ± 0.034	0.387 ± 0.028	0.410 ± 0.024
≥11.0	0.418 ± 0.030	0.414 ± 0.030	0.440 ± 0.042	0.415 ± 0.030	0.445 ± 0.034	0.416 ± 0.030	0.438 ± 0.033
				Bark			
5.0-10.9	0.350 ± 0.029	--	--	0.367 ± 0.029	0.336 ± 0.037	0.382 ± 0.032	0.248 ± 0.057
≥11.0	0.341 ± 0.047	0.340 ± 0.047	0.379 ± 0.046	0.344 ± 0.047	0.358 ± 0.050	0.346 ± 0.045	0.312 ± 0.059
				Wood and Bark			
5.0-10.9	0.383 ± 0.025	--	--	0.385 ± 0.026	0.385 ± 0.029	0.387 ± 0.026	0.360 ± 0.024
≥11.0	0.406 ± 0.020	0.403 ± 0.028	0.429 ± 0.038	0.405 ± 0.028	0.428 ± 0.032	0.405 ± 0.028	0.400 ± 0.036
				HARD HARDWOODS			
				Wood			
5.0-10.9	0.598 ± 0.048	--	--	0.596 ± 0.053	0.619 ± 0.037	0.598 ± 0.047	0.606 ± 0.039
≥11.0	0.604 ± 0.041	0.596 ± 0.046	0.616 ± 0.044	0.598 ± 0.045	0.630 ± 0.037	0.598 ± 0.045	0.622 ± 0.040

Continued

Table 2.--Average specific gravity of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Southern Appalachian Mountains--Continued

Tree size class (inches)	Average and standard deviation						
		Stem					
	Total tree	Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	Branches
				Bark			
5.0-10.9	0.502 ± 0.096	--	--	0.510 ± 0.119	0.514 ± 0.087	0.510 ± 0.113	0.476 ± 0.070
≥11.0	0.536 ± 0.093	0.545 ± 0.109	0.558 ± 0.107	0.548 ± 0.108	0.532 ± 0.077	0.548 ± 0.107	0.516 ± 0.079
				Wood and Bark			
5.0-10.9	0.582 ± 0.043	--	--	0.578 ± 0.053	0.592 ± 0.034	0.584 ± 0.044	0.563 ± 0.036
≥11.0	0.594 ± 0.033	0.586 ± 0.039	0.601 ± 0.040	0.587 ± 0.038	0.600 ± 0.034	0.591 ± 0.038	0.588 ± 0.038
				WHITE ASH			
				Wood			
5.0-10.9	0.589 ± 0.031	--	--	0.589 ± 0.035	0.613 ± 0.035	0.590 ± 0.034	0.590 ± 0.028
≥11.0	0.579 ± 0.040	0.572 ± 0.043	0.603 ± 0.043	0.576 ± 0.042	0.622 ± 0.044	0.576 ± 0.042	0.598 ± 0.044
				Bark			
5.0-10.9	0.407 ± 0.041	--	--	0.375 ± 0.056	0.441 ± 0.039	0.383 ± 0.053	0.461 ± 0.032
≥11.0	0.407 ± 0.044	0.384 ± 0.043	0.405 ± 0.055	0.387 ± 0.044	0.446 ± 0.047	0.388 ± 0.044	0.440 ± 0.046
				Wood and Bark			
5.0-10.9	0.562 ± 0.031	--	--	0.551 ± 0.036	0.569 ± 0.033	0.558 ± 0.034	0.549 ± 0.027
≥11.0	0.556 ± 0.037	0.544 ± 0.038	0.562 ± 0.045	0.546 ± 0.037	0.567 ± 0.046	0.552 ± 0.039	0.549 ± 0.044
				SWEET BIRCH			
				Wood			
5.0-10.9	0.531 ± 0.095	--	--	0.541 ± 0.107	0.608 ± 0.023	0.555 ± 0.080	0.571 ± 0.021
≥11.0	0.602 ± 0.025	0.601 ± 0.027	0.611 ± 0.027	0.602 ± 0.026	0.618 ± 0.029	0.602 ± 0.026	0.601 ± 0.026
				Bark			
5.0-10.9	0.556 ± 0.084	--	--	0.619 ± 0.144	0.633 ± 0.030	0.624 ± 0.105	0.511 ± 0.026
≥11.0	0.663 ± 0.027	0.716 ± 0.025	0.719 ± 0.030	0.717 ± 0.025	0.679 ± 0.026	0.716 ± 0.025	0.594 ± 0.039
				Wood and Bark			
5.0-10.9	0.536 ± 0.092	--	--	0.550 ± 0.112	0.612 ± 0.020	0.564 ± 0.082	0.551 ± 0.019
≥11.0	0.614 ± 0.020	0.616 ± 0.023	0.628 ± 0.022	0.617 ± 0.022	0.630 ± 0.022	0.618 ± 0.021	0.598 ± 0.025

Continued

Table 2.--Average specific gravity of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Southern Appalachian Mountains--Continued

Tree size class (inches)	Average and standard deviation						
		Stem					
	Total tree	Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	Branches
BLACK LOCUST							
				Wood			
5.0-10.9	0.600 ± 0.059	--	--	0.583 ± 0.087	0.548 ± 0.016	0.596 ± 0.070	0.621 ± 0.046
≥11.0	0.655 ± 0.032	0.648 ± 0.037	0.664 ± 0.033	0.652 ± 0.035	0.676 ± 0.033	0.652 ± 0.035	0.666 ± 0.026
				Bark			
5.0-10.9	0.289 ± 0.026	--	--	0.266 ± 0.040	0.328 ± 0.018	0.277 ± 0.032	0.329 ± 0.021
≥11.0	0.305 ± 0.027	0.282 ± 0.024	0.317 ± 0.030	0.293 ± 0.025	0.346 ± 0.030	0.295 ± 0.025	0.335 ± 0.031
				Wood and Bark			
5.0-10.9	0.554 ± 0.055	--	--	0.508 ± 0.079	0.564 ± 0.029	0.551 ± 0.068	0.514 ± 0.037
≥11.0	0.605 ± 0.025	0.561 ± 0.020	0.568 ± 0.021	0.565 ± 0.017	0.570 ± 0.026	0.606 ± 0.027	0.542 ± 0.024
HICKORY							
				Wood			
5.0-10.9	0.657 ± 0.033	--	--	0.660 ± 0.031	0.666 ± 0.044	0.659 ± 0.033	0.640 ± 0.051
≥11.0	0.648 ± 0.033	0.646 ± 0.039	0.661 ± 0.038	0.649 ± 0.037	0.657 ± 0.047	0.649 ± 0.036	0.647 ± 0.037
				Bark			
5.0-10.9	0.503 ± 0.027	--	--	0.523 ± 0.028	0.493 ± 0.031	0.519 ± 0.027	0.445 ± 0.040
≥11.0	0.531 ± 0.036	0.550 ± 0.039	0.561 ± 0.037	0.552 ± 0.036	0.520 ± 0.032	0.552 ± 0.036	0.497 ± 0.044
				Wood and Bark			
5.0-10.9	0.632 ± 0.030	--	--	0.636 ± 0.030	0.625 ± 0.036	0.636 ± 0.032	0.574 ± 0.040
≥11.0	0.629 ± 0.029	0.631 ± 0.034	0.642 ± 0.031	0.634 ± 0.031	0.615 ± 0.037	0.635 ± 0.031	0.599 ± 0.033
BLACK OAK							
				Wood			
5.0-10.9	0.579 ± 0.025	--	--	0.570 ± 0.026	0.606 ± 0.024	0.572 ± 0.025	0.623 ± 0.034
≥11.0	0.573 ± 0.038	0.556 ± 0.044	0.579 ± 0.039	0.560 ± 0.044	0.623 ± 0.029	0.560 ± 0.044	0.613 ± 0.033
				Bark			
5.0-10.9	0.533 ± 0.035	--	--	0.552 ± 0.038	0.538 ± 0.042	0.550 ± 0.038	0.433 ± 0.048
≥11.0	0.573 ± 0.032	0.584 ± 0.032	0.601 ± 0.035	0.587 ± 0.030	0.565 ± 0.037	0.586 ± 0.030	0.542 ± 0.052

Continued

Table 2.--Average specific gravity of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Southern Appalachian Mountains--Continued

Tree size class (inches)	Average and standard deviation						
		Stem					
	Total tree	Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	Branches
				Wood and Bark			
5.0-10.9	0.570 ± 0.022	--	--	0.566 ± 0.022	0.591 ± 0.023	0.569 ± 0.021	0.557 ± 0.036
≥11.0	0.574 ± 0.030	0.561 ± 0.036	0.583 ± 0.025	0.564 ± 0.035	0.608 ± 0.021	0.564 ± 0.035	0.591 ± 0.020
				CHESTNUT OAK			
				Wood			
5.0-10.9	0.608 ± 0.022	--	--	0.612 ± 0.022	0.603 ± 0.026	0.610 ± 0.022	0.592 ± 0.033
≥11.0	0.620 ± 0.023	0.620 ± 0.023	0.622 ± 0.031	0.620 ± 0.023	0.620 ± 0.033	0.620 ± 0.023	0.620 ± 0.052
				Bark			
5.0-10.9	0.500 ± 0.039	--	--	0.508 ± 0.045	0.488 ± 0.041	0.505 ± 0.044	0.474 ± 0.033
≥11.0	0.506 ± 0.035	0.515 ± 0.042	0.507 ± 0.042	0.513 ± 0.042	0.497 ± 0.037	0.513 ± 0.041	0.488 ± 0.031
				Wood and Bark			
5.0-10.9	0.585 ± 0.025	--	--	0.586 ± 0.028	0.567 ± 0.026	0.589 ± 0.026	0.549 ± 0.029
≥11.0	0.598 ± 0.021	0.599 ± 0.021	0.589 ± 0.028	0.598 ± 0.022	0.576 ± 0.025	0.602 ± 0.021	0.572 ± 0.040
				NORTHERN RED OAK			
				Wood			
5.0-10.9	0.581 ± 0.020	--	--	0.577 ± 0.020	0.606 ± 0.025	0.578 ± 0.019	0.600 ± 0.031
≥11.0	0.580 ± 0.021	0.568 ± 0.022	0.608 ± 0.026	0.571 ± 0.022	0.609 ± 0.009	0.571 ± 0.022	0.610 ± 0.022
				Bark			
5.0-10.9	0.610 ± 0.022	--	--	0.624 ± 0.025	0.607 ± 0.026	0.623 ± 0.024	0.561 ± 0.037
≥11.0	0.623 ± 0.032	0.634 ± 0.038	0.658 ± 0.038	0.636 ± 0.036	0.590 ± 0.006	0.635 ± 0.036	0.596 ± 0.056
				Wood and Bark			
5.0-10.9	0.586 ± 0.018	--	--	0.583 ± 0.018	0.606 ± 0.021	0.585 ± 0.017	0.590 ± 0.029
≥11.0	0.587 ± 0.019	0.576 ± 0.021	0.616 ± 0.025	0.579 ± 0.022	0.608 ± 0.007	0.579 ± 0.022	0.607 ± 0.024
				SCARLET OAK			
				Wood			
5.0-10.9	0.576 ± 0.029	--	--	0.563 ± 0.035	0.594 ± 0.026	0.565 ± 0.035	0.619 ± 0.011
≥11.0	0.578 ± 0.024	0.558 ± 0.025	0.564 ± 0.027	0.559 ± 0.025	0.635 ± 0.025	0.560 ± 0.025	0.629 ± 0.027

Continued

Table 2.--Average specific gravity of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Southern Appalachian Mountains--Continued

Tree size class (inches)	Average and standard deviation						
		Stem					
	Total tree	Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	Branches
				Bark			
5.0-10.9	0.555 ± 0.045	--	--	0.595 ± 0.028	0.555 ± 0.043	0.590 ± 0.030	0.476 ± 0.067
≥11.0	0.613 ± 0.037	0.635 ± 0.035	0.639 ± 0.037	0.636 ± 0.034	0.581 ± 0.037	0.635 ± 0.034	0.575 ± 0.044
				Wood and Bark			
5.0-10.9	0.572 ± 0.021	--	--	0.568 ± 0.029	0.587 ± 0.024	0.569 ± 0.028	0.572 ± 0.027
≥11.0	0.584 ± 0.019	0.568 ± 0.021	0.575 ± 0.022	0.569 ± 0.021	0.623 ± 0.021	0.570 ± 0.021	0.614 ± 0.022
				WHITE OAK			
				Wood			
5.0-10.9	0.629 ± 0.026	--	--	0.630 ± 0.028	0.633 ± 0.021	0.630 ± 0.026	0.623 ± 0.039
≥11.0	0.608 ± 0.026	0.595 ± 0.028	0.623 ± 0.034	0.596 ± 0.028	0.637 ± 0.031	0.596 ± 0.028	0.637 ± 0.033
				Bark			
5.0-10.9	0.477 ± 0.038	--	--	0.492 ± 0.043	0.490 ± 0.045	0.490 ± 0.044	0.443 ± 0.036
≥11.0	0.518 ± 0.033	0.533 ± 0.045	0.555 ± 0.040	0.536 ± 0.040	0.531 ± 0.029	0.536 ± 0.040	0.494 ± 0.036
				Wood and Bark			
5.0-10.9	0.607 ± 0.025	--	--	0.610 ± 0.027	0.598 ± 0.022	0.612 ± 0.025	0.562 ± 0.034
≥11.0	0.594 ± 0.022	0.587 ± 0.023	0.609 ± 0.029	0.588 ± 0.023	0.605 ± 0.024	0.589 ± 0.024	0.594 ± 0.029
				ALL SPECIES			
				Wood			
5.0-10.9	0.550 ± 0.092	--	--	0.550 ± 0.093	0.565 ± 0.097	0.551 ± 0.092	0.557 ± 0.091
≥11.0	0.563 ± 0.085	0.557 ± 0.085	0.574 ± 0.087	0.558 ± 0.085	0.586 ± 0.088	0.551 ± 0.091	0.579 ± 0.089
				Bark			
5.0-10.9	0.484 ± 0.099	--	--	0.494 ± 0.116	0.491 ± 0.099	0.496 ± 0.110	0.447 ± 0.098
≥11.0	0.502 ± 0.109	0.510 ± 0.123	0.524 ± 0.118	0.513 ± 0.122	0.502 ± 0.095	0.513 ± 0.120	0.481 ± 0.102
				Wood and Bark			
5.0-10.9	0.540 ± 0.084	--	--	0.538 ± 0.086	0.546 ± 0.085	0.542 ± 0.084	0.521 ± 0.082
≥11.0	0.554 ± 0.081	0.547 ± 0.081	0.562 ± 0.081	0.549 ± 0.080	0.562 ± 0.078	0.552 ± 0.081	0.547 ± 0.084

Table 3.--Average moisture content of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Southern Appalachian Mountains

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Percent						
SOFT HARDWOODS							
Wood							
5.0-10.9	105 ± 19.1	--	--	105 ± 19.9	103 ± 19.0	105 ± 19.1	107 ± 22.0
≥11.0	99 ± 15.8	98 ± 15.8	95 ± 16.6	98 ± 15.6	104 ± 18.3	98 ± 15.6	107 ± 21.2
Bark							
5.0-10.9	109 ± 48.7	--	--	96 ± 42.6	125 ± 66.5	106 ± 55.4	164 ± 99.4
≥11.0	96 ± 27.7	87 ± 26.6	84 ± 22.6	86 ± 25.7	125 ± 48.1	88 ± 26.7	145 ± 61.6
Wood and Bark							
5.0-10.9	104 ± 20.4	--	--	103 ± 20.7	105 ± 21.3	105 ± 21.6	124 ± 37.7
≥11.0	98 ± 14.9	96 ± 15.0	93 ± 14.8	95 ± 14.6	106 ± 20.1	96 ± 14.7	119 ± 27.8
BASSWOOD							
Wood							
5.0-10.9	126 ± 16.2	--	--	125 ± 17.9	123 ± 12.7	125 ± 17.2	136 ± 13.6
≥11.0	119 ± 11.7	120 ± 12.9	111 ± 13.5	118 ± 12.1	115 ± 13.2	118 ± 12.0	129 ± 14.8
Bark							
5.0-10.9	97 ± 6.6	--	--	90 ± 4.8	101 ± 9.8	91 ± 4.3	113 ± 9.9
≥11.0	96 ± 6.8	85 ± 9.9	86 ± 10.3	85 ± 9.7	104 ± 11.8	85 ± 9.6	119 ± 11.6
Wood and Bark							
5.0-10.9	118 ± 12.0	--	--	118 ± 15.1	117 ± 8.2	118 ± 14.1	127 ± 8.0
≥11.0	114 ± 9.9	115 ± 11.6	106 ± 11.2	113 ± 10.6	112 ± 11.9	113 ± 10.6	126 ± 12.9
BLACKGUM							
Wood							
5.0-10.9	107 ± 7.8	--	--	106 ± 9.1	110 ± 7.5	106 ± 8.8	112 ± 6.3
≥11.0	98 ± 14.2	94 ± 12.2	98 ± 18.0	95 ± 13.9	101 ± 16.4	95 ± 14.0	109 ± 16.5
Bark							
5.0-10.9	54 ± 7.6	--	--	49 ± 8.3	56 ± 6.4	49 ± 8.2	63 ± 6.0
≥11.0	52 ± 9.1	49 ± 13.5	50 ± 13.0	49 ± 13.2	61 ± 9.7	49 ± 12.9	59 ± 7.7
Wood and Bark							
5.0-10.9	95 ± 6.2	--	--	93 ± 6.3	94 ± 5.5	97 ± 7.1	96 ± 7.2
≥11.0	87 ± 7.4	85 ± 6.2	87 ± 11.6	86 ± 7.5	88 ± 7.8	88 ± 9.1	93 ± 11.2
RED MAPLE							
Wood							
5.0-10.9	83 ± 5.3	--	--	83 ± 6.5	83 ± 6.9	83 ± 6.2	82 ± 11.9
≥11.0	76 ± 7.3	77 ± 7.2	73 ± 7.6	76 ± 7.1	76 ± 8.8	76 ± 7.1	77 ± 10.4

Continued

Table 3.--Average moisture content of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Southern Appalachian Mountains--Continued

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Percent						
				Bark			
5.0-10.9	74 ± 9.4	--	--	64 ± 7.0	77 ± 11.9	66 ± 6.9	95 ± 14.4
≥11.0	72 ± 7.3	61 ± 7.6	64 ± 9.3	62 ± 7.2	78 ± 8.4	62 ± 7.1	85 ± 11.5
				Wood and Bark			
5.0-10.9	81 ± 4.8	--	--	81 ± 5.2	82 ± 6.2	81 ± 5.1	85 ± 12.3
≥11.0	76 ± 6.8	76 ± 6.9	72 ± 7.7	75 ± 6.9	76 ± 7.7	75 ± 6.8	79 ± 9.1
				YELLOW-POPLAR			
				Wood			
5.0-10.9	113 ± 13.5	--	--	115 ± 14.8	109 ± 17.0	113 ± 13.7	112 ± 13.9
≥11.0	101 ± 9.4	100 ± 10.0	98 ± 12.0	100 ± 9.8	111 ± 12.4	100 ± 9.8	111 ± 15.4
				Bark			
5.0-10.9	160 ± 33.1	--	--	140 ± 29.6	196 ± 44.5	162 ± 43.7	271 ± 66.8
≥11.0	115 ± 17.8	104 ± 18.4	99 ± 14.2	103 ± 17.4	160 ± 32.6	105 ± 18.6	190 ± 40.3
				Wood and Bark			
5.0-10.9	120 ± 14.5	--	--	118 ± 15.0	121 ± 17.1	121 ± 16.4	162 ± 22.2
≥11.0	103 ± 8.5	101 ± 9.1	98 ± 10.2	100 ± 8.7	119 ± 11.6	101 ± 9.0	135 ± 18.4
				HARD HARDWOODS			
				Wood			
5.0-10.9	62 ± 14.4	--	--	64 ± 15.7	59 ± 11.8	63 ± 15.2	58 ± 10.7
≥11.0	67 ± 14.0	71 ± 15.7	63 ± 13.5	70 ± 15.5	59 ± 10.0	70 ± 15.5	60 ± 10.2
				Bark			
5.0-10.9	69 ± 15.1	--	--	64 ± 16.0	72 ± 15.5	66 ± 16.5	81 ± 17.2
≥11.0	65 ± 10.6	62 ± 11.0	60 ± 11.8	62 ± 10.7	70 ± 12.3	62 ± 10.5	71 ± 13.8
				Wood and Bark			
5.0-10.9	63 ± 11.7	--	--	64 ± 12.7	62 ± 8.2	64 ± 12.3	66 ± 8.2
≥11.0	67 ± 11.2	69 ± 12.9	63 ± 10.5	69 ± 12.7	62 ± 7.2	69 ± 12.9	63 ± 7.7
				WHITE ASH			
				Wood			
5.0-10.9	45 ± 2.3	--	--	45 ± 2.5	43 ± 2.3	45 ± 2.5	43 ± 3.0
≥11.0	46 ± 3.0	47 ± 4.1	44 ± 2.7	46 ± 3.2	45 ± 3.3	46 ± 3.2	45 ± 3.8
				Bark			
5.0-10.9	84 ± 19.5	--	--	82 ± 22.1	86 ± 18.5	84 ± 22.8	86 ± 19.0
≥11.0	78 ± 11.2	77 ± 11.8	77 ± 17.0	77 ± 12.3	80 ± 16.5	77 ± 11.9	78 ± 16.4

Continued

Table 3.--Average moisture content of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Southern Appalachian Mountains--Continued

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Percent						
				Wood and Bark			
5.0-10.9	51 ± 3.5	--	--	52 ± 5.2	53 ± 4.8	51 ± 4.4	57 ± 6.5
≥11.0	51 ± 3.6	52 ± 4.4	50 ± 5.1	51 ± 3.9	55 ± 6.2	51 ± 3.8	55 ± 6.1
				SWEET BIRCH			
				Wood			
5.0-10.9	62 ± 11.3	--	--	64 ± 11.6	70 ± 2.6	66 ± 8.5	62 ± 5.7
≥11.0	71 ± 4.0	72 ± 4.3	71 ± 2.6	72 ± 3.5	70 ± 3.9	72 ± 3.4	69 ± 7.2
				Bark			
5.0-10.9	66 ± 6.7	--	--	53 ± 11.1	66 ± 3.3	56 ± 6.8	84 ± 8.0
≥11.0	58 ± 4.7	53 ± 3.9	52 ± 4.1	53 ± 3.9	57 ± 4.5	53 ± 3.8	65 ± 6.4
				Wood and Bark			
5.0-10.9	62 ± 10.3	--	--	62 ± 11.5	69 ± 2.5	64 ± 8.2	69 ± 5.1
≥11.0	69 ± 3.0	70 ± 3.7	68 ± 2.5	70 ± 3.2	67 ± 2.9	70 ± 3.1	68 ± 3.8
				BLACK LOCUST			
				Wood			
5.0-10.9	44 ± 6.5	--	--	42 ± 8.2	46 ± 3.5	43 ± 6.9	50 ± 6.6
≥11.0	49 ± 10.5	52 ± 12.2	46 ± 10.3	50 ± 11.5	44 ± 7.6	50 ± 11.4	44 ± 6.1
				Bark			
5.0-10.9	57 ± 20.5	--	--	56 ± 19.4	63 ± 19.2	54 ± 22.9	67 ± 20.2
≥11.0	55 ± 11.4	57 ± 14.5	54 ± 11.7	56 ± 13.2	57 ± 9.5	56 ± 13.0	56 ± 9.6
				Wood and Bark			
5.0-10.9	46 ± 6.9	--	--	45 ± 10.2	51 ± 6.0	45 ± 7.5	57 ± 8.1
≥11.0	50 ± 9.5	53 ± 10.8	48 ± 7.9	51 ± 9.9	48 ± 6.1	51 ± 10.4	48 ± 5.4
				HICKORY			
				Wood			
5.0-10.9	51 ± 3.1	--	--	52 ± 3.5	47 ± 2.8	51 ± 3.4	47 ± 2.5
≥11.0	55 ± 5.5	58 ± 6.6	52 ± 6.2	57 ± 6.4	50 ± 3.9	57 ± 6.4	50 ± 3.9
				Bark			
5.0-10.9	72 ± 11.1	--	--	67 ± 9.0	80 ± 14.8	68 ± 9.8	88 ± 15.0
≥11.0	70 ± 11.1	66 ± 10.5	62 ± 10.6	65 ± 10.0	76 ± 15.1	65 ± 10.0	77 ± 15.1
				Wood and Bark			
5.0-10.9	54 ± 3.4	--	--	54 ± 3.8	55 ± 4.8	54 ± 3.6	61 ± 5.6
≥11.0	58 ± 4.9	59 ± 5.5	54 ± 5.2	58 ± 5.3	58 ± 6.7	58 ± 5.4	59 ± 7.2

Continued

Table 3.--Average moisture content of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Southern Appalachian Mountains--Continued

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Percent						
BLACK OAK							
Wood							
5.0-10.9	75 ± 6.7	--	--	78 ± 8.4	67 ± 4.0	77 ± 7.8	62 ± 3.8
≥11.0	81 ± 10.2	87 ± 12.2	79 ± 10.0	86 ± 12.2	66 ± 6.7	86 ± 12.1	67 ± 7.2
Bark							
5.0-10.9	69 ± 5.5	--	--	61 ± 5.4	75 ± 8.4	63 ± 6.2	103 ± 12.6
≥11.0	62 ± 9.3	57 ± 8.4	55 ± 8.3	57 ± 8.0	69 ± 11.2	57 ± 8.1	73 ± 15.3
Wood and Bark							
5.0-10.9	74 ± 4.7	--	--	75 ± 6.4	68 ± 2.7	75 ± 6.1	76 ± 5.8
≥11.0	77 ± 7.8	82 ± 9.8	74 ± 7.0	81 ± 9.6	66 ± 5.3	81 ± 9.7	69 ± 5.1
CHESTNUT OAK							
Wood							
5.0-10.9	67 ± 3.4	--	--	67 ± 4.3	64 ± 3.1	67 ± 4.0	66 ± 5.5
≥11.0	68 ± 4.4	70 ± 4.7	62 ± 4.9	69 ± 4.7	62 ± 4.3	69 ± 4.7	62 ± 4.6
Bark							
5.0-10.9	53 ± 7.6	--	--	49 ± 6.6	55 ± 9.3	50 ± 6.0	70 ± 14.2
≥11.0	59 ± 6.5	58 ± 7.9	55 ± 7.7	58 ± 6.6	63 ± 9.7	58 ± 6.6	64 ± 11.0
Wood and Bark							
5.0-10.9	64 ± 3.6	--	--	63 ± 4.6	61 ± 3.6	64 ± 3.9	68 ± 5.3
≥11.0	66 ± 3.9	67 ± 4.4	60 ± 4.5	67 ± 4.2	62 ± 4.7	67 ± 4.2	63 ± 5.3
NORTHERN RED OAK							
Wood							
5.0-10.9	79 ± 4.0	--	--	81 ± 4.5	69 ± 3.7	80 ± 4.5	68 ± 3.6
≥11.0	81 ± 5.5	86 ± 5.8	72 ± 4.7	84 ± 5.8	68 ± 4.5	84 ± 5.8	69 ± 4.6
Bark							
5.0-10.9	65 ± 4.7	--	--	64 ± 5.3	67 ± 4.9	64 ± 5.0	71 ± 7.9
≥11.0	60 ± 5.6	58 ± 6.0	55 ± 4.8	58 ± 5.7	70 ± 4.4	59 ± 5.7	64 ± 10.4
Wood and Bark							
5.0-10.9	76 ± 3.6	--	--	79 ± 4.1	69 ± 3.2	78 ± 4.0	69 ± 4.0
≥11.0	78 ± 5.0	82 ± 5.6	69 ± 4.5	81 ± 5.5	68 ± 4.3	81 ± 5.5	68 ± 4.5
SCARLET OAK							
Wood							
5.0-10.9	76 ± 2.9	--	--	80 ± 3.1	71 ± 2.7	80 ± 3.2	64 ± 3.5
≥11.0	80 ± 5.3	87 ± 6.0	81 ± 6.3	86 ± 6.0	64 ± 3.9	85 ± 6.1	65 ± 4.0

Continued

Table 3.--Average moisture content of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Southern Appalachian Mountains--Continued

Tree size class (inches)	Average and standard deviation						
		Stem					
	Total tree	Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	Branches
	Percent						
				Bark			
5.0-10.9	71 ± 11.6	--	--	63 ± 7.8	72 ± 11.0	64 ± 8.4	87 ± 16.9
≥11.0	63 ± 5.6	60 ± 5.2	60 ± 5.0	60 ± 4.9	66 ± 6.3	60 ± 4.9	69 ± 7.2
				Wood and Bark			
5.0-10.9	75 ± 3.2	--	--	77 ± 3.4	71 ± 3.8	77 ± 3.3	72 ± 5.3
≥11.0	77 ± 4.2	83 ± 5.3	78 ± 5.3	82 ± 5.3	65 ± 3.3	82 ± 5.3	66 ± 3.1
				WHITE OAK			
				Wood			
5.0-10.9	65 ± 4.3	--	--	66 ± 4.6	65 ± 4.5	66 ± 4.5	64 ± 5.0
≥11.0	72 ± 4.8	76 ± 5.8	65 ± 4.1	75 ± 6.0	63 ± 4.0	75 ± 6.0	63 ± 3.4
				Bark			
5.0-10.9	71 ± 7.0	--	--	62 ± 5.3	73 ± 9.0	64 ± 5.6	91 ± 10.7
≥11.0	74 ± 5.9	69 ± 8.1	65 ± 7.8	68 ± 6.8	71 ± 6.2	68 ± 6.7	81 ± 7.4
				Wood and Bark			
5.0-10.9	66 ± 4.4	--	--	65 ± 4.3	66 ± 4.5	66 ± 4.3	73 ± 5.3
≥11.0	72 ± 3.7	75 ± 4.7	65 ± 3.5	74 ± 4.9	65 ± 3.6	74 ± 4.9	68 ± 3.4
				ALL SPECIES			
				Wood			
5.0-10.9	75 ± 25.3	--	--	76 ± 25.6	72 ± 24.9	76 ± 25.1	72 ± 26.8
≥11.0	75 ± 19.8	78 ± 19.7	71 ± 20.0	77 ± 19.6	70 ± 23.1	77 ± 19.6	72 ± 24.8
				Bark			
5.0-10.9	81 ± 34.6	--	--	74 ± 30.3	88 ± 45.3	78 ± 37.8	105 ± 67.2
≥11.0	73 ± 21.4	69 ± 19.4	66 ± 18.5	68 ± 18.9	83 ± 35.5	69 ± 19.5	89 ± 46.0
				Wood and Bark			
5.0-10.9	75 ± 24.0	--	--	76 ± 23.7	74 ± 23.8	76 ± 24.5	83 ± 34.3
≥11.0	74 ± 18.1	76 ± 17.8	70 ± 17.6	76 ± 17.5	73 ± 22.5	76 ± 17.9	77 ± 28.5

Table 4.--Average proportion of wood and bark green weight in bark, by tree component and size class, for hardwood species in the Southern Appalachian Mountains

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Percent						
SOFT HARDWOODS							
5.0-10.9	18 ± 3.1	--	--	15 ± 2.8	20 ± 4.6	16 ± 2.8	31 ± 6.2
≥11.0	17 ± 2.4	13 ± 3.0	18 ± 4.1	14 ± 2.8	22 ± 6.7	15 ± 2.8	30 ± 5.0
BASSWOOD							
5.0-10.9	22 ± 2.3	--	--	18 ± 2.1	27 ± 3.4	19 ± 2.4	39 ± 4.6
≥11.0	19 ± 2.1	14 ± 1.6	19 ± 1.4	15 ± 1.7	29 ± 1.9	15 ± 1.7	36 ± 4.1
BLACKGUM							
5.0-10.9	18 ± 1.1	--	--	15 ± 1.5	22 ± 3.6	16 ± 1.4	26 ± 3.3
≥11.0	16 ± 4.5	13 ± 5.1	16 ± 5.3	14 ± 5.0	23 ± 5.4	14 ± 5.0	25 ± 4.0
RED MAPLE							
5.0-10.9	16 ± 2.1	--	--	12 ± 2.1	18 ± 3.2	13 ± 2.4	27 ± 4.4
≥11.0	15 ± 1.0	11 ± 1.7	17 ± 4.9	11 ± 1.6	22 ± 3.5	11 ± 1.6	27 ± 3.3
YELLOW-POPLAR							
5.0-10.9	19 ± 2.6	--	--	16 ± 2.1	17 ± 2.4	16 ± 1.9	33 ± 4.2
≥11.0	17 ± 1.7	14± 1.6	20 ± 2.8	15 ± 1.7	19 ± 7.0	15 ± 1.7	31 ± 3.9
HARD HARDWOODS							
5.0-10.9	18 ± 3.3	--	--	15 ± 3.5	22 ± 5.1	16 ± 3.6	29 ± 5.2
≥11.0	17 ± 2.8	13 ± 2.5	18 ± 4.6	14 ± 2.6	26 ± 8.9	14 ± 2.6	27 ± 4.5
WHITE ASH							
5.0-10.9	18 ± 3.5	--	--	15 ± 3.3	25 ± 6.2	15 ± 3.5	32 ± 4.5
≥11.0	16 ± 2.2	12 ± 1.9	18 ± 3.8	13 ± 1.9	30 ± 6.6	13 ± 2.0	30 ± 3.9
SWEET BIRCH							
5.0-10.9	18 ± 1.2	--	--	12 ± 1.4	19 ± 2.3	13 ± 1.4	33 ± 3.0
≥11.0	18 ± 3.0	14 ± 2.6	17 ± 4.2	14 ± 2.8	22 ± 4.3	14 ± 2.8	28 ± 5.1
BLACK LOCUST							
5.0-10.9	16 ± 4.9	--	--	13 ± 5.6	19 ± 5.4	14 ± 5.5	25 ± 4.2
≥11.0	15 ± 1.9	12 ± 1.4	16 ± 2.1	13 ± 1.4	24 ± 3.3	13 ± 1.5	25 ± 4.5
HICKORY							
5.0-10.9	19 ± 2.9	--	--	16 ± 3.0	24 ± 5.1	17 ± 3.5	32 ± 5.7
≥11.0	18 ± 3.0	13 ± 2.6	17 ± 3.6	14 ± 2.6	32 ± 8.6	14 ± 2.6	29 ± 4.2

Continued

Table 4.--Average proportion of wood and bark green weight in bark, by tree component and size class, for hardwood species in the Southern Appalachian Mountains--Continued

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Percent						
BLACK OAK							
5.0-10.9	19 ± 2.3	--	--	17 ± 2.3	24 ± 2.4	18 ± 2.4	31 ± 2.7
≥11.0	18 ± 2.1	14 ± 2.1	18 ± 2.4	15 ± 2.1	27 ± 3.6	15 ± 2.0	28 ± 2.6
CHESTNUT OAK							
5.0-10.9	21 ± 3.5	--	--	19 ± 3.7	27 ± 4.8	20 ± 3.5	31 ± 7.0
≥11.0	20 ± 2.7	16 ± 2.6	24 ± 5.1	17 ± 2.7	34 ± 8.4	17 ± 2.7	31 ± 3.6
NORTHERN RED OAK							
5.0-10.9	16 ± 1.3	--	--	14 ± 1.2	19 ± 2.3	14 ± 1.3	25 ± 2.1
≥11.0	15 ± 1.3	12 ± 1.4	16 ± 2.8	12 ± 1.3	15 ± 2.0	12 ± 1.3	23 ± 2.1
SCARLET OAK							
5.0-10.9	20 ± 2.8	--	--	26 ± 2.1	22 ± 1.6	17 ± 2.1	29 ± 2.2
≥11.0	15 ± 1.1	12 ± 1.1	15 ± 1.8	12 ± 1.2	22 ± 2.8	13 ± 1.2	24 ± 2.8
WHITE OAK							
5.0-10.9	16 ± 2.6	--	--	12 ± 2.2	22 ± 3.5	13 ± 2.0	30 ± 2.6
≥11.0	16 ± 2.0	12 ± 1.8	18 ± 3.8	12 ± 1.8	29 ± 7.0	12 ± 1.8	26 ± 3.8
ALL SPECIES							
5.0-10.9	18 ± 3.2	--	--	15 ± 3.3	22 ± 5.1	16 ± 3.4	30 ± 5.6
≥11.0	17 ± 2.7	13 ± 2.6	18 ± 4.5	14 ± 2.6	25 ± 8.7	14 ± 2.6	28 ± 4.8

Table 5.--Average green weight per cubic foot of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Southern Appalachian Mountains

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Pounds per cubic foot						
SOFT HARDWOODS							
Wood							
5.0-10.9	56 ± 6.3	--	--	56 ± 6.2	56 ± 7.4	56 ± 6.2	56 ± 7.1
≥11.0	54 ± 5.1	55 ± 5.5	55 ± 5.3	53 ± 5.1	58 ± 8.6	53 ± 5.1	57 ± 6.3
Bark							
5.0-10.9	55 ± 6.0	--	--	54 ± 7.4	57 ± 6.6	53 ± 7.0	57 ± 4.7
≥11.0	48 ± 6.3	48 ± 7.2	50 ± 8.3	46 ± 7.3	54 ± 5.6	46 ± 7.3	56 ± 5.7
Wood and Bark							
5.0-10.9	55 ± 4.7	--	--	55 ± 4.8	54 ± 5.3	55 ± 4.8	56 ± 4.7
≥11.0	53 ± 4.4	54 ± 4.7	54 ± 4.3	52 ± 4.6	54 ± 5.3	52 ± 4.6	57 ± 4.5
BASSWOOD							
Wood							
5.0-10.9	51 ± 1.5	--	--	53 ± 1.8	46 ± 3.1	52 ± 1.7	47 ± 2.6
≥11.0	49 ± 3.7	50 ± 4.2	49 ± 2.1	50 ± 3.8	46 ± 3.0	49 ± 3.7	48 ± 4.3
Bark							
5.0-10.9	51 ± 2.4	--	--	50 ± 2.5	52 ± 3.2	50 ± 2.4	54 ± 2.8
≥11.0	50 ± 1.5	49 ± 2.7	48 ± 2.7	48 ± 2.7	51 ± 2.2	49 ± 2.6	54 ± 2.0
Wood and Bark							
5.0-10.9	51 ± 1.1	--	--	52 ± 1.3	47 ± 2.1	52 ± 1.2	50 ± 2.3
≥11.0	49 ± 3.2	49 ± 3.8	48 ± 1.5	49 ± 3.3	47 ± 2.0	49 ± 3.3	50 ± 3.3
BLACKGUM							
Wood							
5.0-10.9	67 ± 4.0	--	--	66 ± 5.0	64 ± 3.2	66 ± 4.7	69 ± 1.6
≥11.0	61 ± 5.6	60 ± 6.4	60 ± 4.3	60 ± 6.0	62 ± 5.0	60 ± 6.0	65 ± 3.8
Bark							
5.0-10.9	45 ± 2.4	--	--	42 ± 2.3	45 ± 2.7	42 ± 2.2	50 ± 3.9
≥11.0	42 ± 3.6	40 ± 4.8	40 ± 6.6	40 ± 5.1	46 ± 4.7	40 ± 4.9	45 ± 2.9
Wood and Bark							
5.0-10.9	61 ± 3.3	--	--	61 ± 4.0	59 ± 2.9	61 ± 3.7	63 ± 2.7
≥11.0	57 ± 4.5	57 ± 5.4	55 ± 3.7	57 ± 5.0	58 ± 4.0	57 ± 5.0	59 ± 3.1
RED MAPLE							
Wood							
5.0-10.9	58 ± 2.7	--	--	59 ± 2.9	55 ± 3.1	58 ± 2.8	56 ± 4.8
≥11.0	57 ± 2.5	57 ± 2.9	55 ± 4.1	57 ± 2.6	54 ± 3.1	57 ± 2.6	56 ± 3.0

Continued

Table 5.--Average green weight per cubic foot of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Southern Appalachian Mountains--Continued

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Pounds per cubic foot						
				Bark			
5.0-10.9	60 ± 3.3	--	--	61 ± 4.4	61 ± 3.2	61 ± 4.0	58 ± 3.5
≥11.0	58 ± 4.2	58 ± 5.0	59 ± 7.5	58 ± 5.2	60 ± 3.2	58 ± 5.1	57 ± 5.3
				Wood and Bark			
5.0-10.9	58 ± 2.4	--	--	59 ± 2.7	56 ± 2.8	58 ± 2.6	56 ± 3.6
≥11.0	57 ± 2.3	57 ± 2.7	55 ± 3.8	57 ± 2.5	55 ± 2.6	57 ± 2.4	57 ± 3.1
				YELLOW-POPLAR			
				Wood			
5.0-10.9	51 ± 3.7	--	--	52 ± 3.7	57 ± 7.6	52 ± 4.3	54 ± 3.7
≥11.0	52 ± 3.7	53 ± 3.1	57 ± 4.2	52 ± 3.6	62 ± 12.9	52 ± 3.7	58 ± 5.3
				Bark			
5.0-10.9	56 ± 4.0	--	--	55 ± 4.6	59 ± 3.5	52 ± 3.7	59 ± 3.7
≥11.0	46 ± 4.1	46 ± 2.5	51 ± 3.4	43 ± 4.1	54 ± 4.3	43 ± 4.2	59 ± 3.3
				Wood and Bark			
5.0-10.9	52 ± 3.4	--	--	52 ± 3.4	52 ± 5.4	52 ± 3.6	56 ± 3.0
≥11.0	51 ± 3.4	52 ± 2.6	56 ± 3.6	50 ± 3.3	55 ± 5.3	50 ± 3.4	58 ± 4.1
				HARD HARDWOODS			
				Wood			
5.0-10.9	62 ± 5.9	--	--	62 ± 6.4	61 ± 9.7	62 ± 6.4	60 ± 4.7
≥11.0	62 ± 4.5	63 ± 4.9	63 ± 5.5	63 ± 4.8	60 ± 5.5	63 ± 4.8	62 ± 4.2
				Bark			
5.0-10.9	53 ± 9.3	--	--	53 ± 11.0	54 ± 8.8	53 ± 10.7	53 ± 7.2
≥11.0	55 ± 8.6	55 ± 9.8	56 ± 9.4	55 ± 9.7	56 ± 7.6	55 ± 9.6	54 ± 7.5
				Wood and Bark			
5.0-10.9	60 ± 5.9	--	--	60 ± 6.6	59 ± 7.6	60 ± 6.5	57 ± 4.5
≥11.0	61 ± 5.0	61 ± 5.3	61 ± 5.9	61 ± 5.3	59 ± 5.2	61 ± 5.2	59 ± 4.9
				WHITE ASH			
				Wood			
5.0-10.9	53 ± 2.7	--	--	53 ± 3.0	54 ± 5.4	53 ± 3.1	53 ± 2.2
≥11.0	52 ± 3.2	52 ± 3.8	55 ± 6.4	52 ± 3.6	58 ± 9.2	52 ± 3.6	54 ± 3.4
				Bark			
5.0-10.9	46 ± 5.3	--	--	43 ± 5.2	51 ± 4.9	44 ± 5.4	53 ± 4.8
≥11.0	45 ± 5.4	42 ± 5.1	45 ± 5.8	42 ± 5.0	49 ± 6.5	43 ± 5.0	49 ± 7.1

Continued

Table 5.--Average green weight per cubic foot of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Southern Appalachian Mountains--Continued

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Pounds per cubic foot						
				Wood and Bark			
5.0-10.9	52 ± 2.7	--	--	51 ± 2.9	53 ± 4.9	51 ± 3.1	53 ± 2.0
≥11.0	51 ± 2.8	50 ± 3.2	53 ± 5.8	50 ± 2.9	55 ± 7.7	50 ± 3.0	52 ± 4.0
				SWEET BIRCH			
				Wood			
5.0-10.9	60 ± 1.7	--	--	60 ± 2.6	63 ± 1.6	61 ± 2.4	58 ± 3.1
≥11.0	63 ± 3.2	63 ± 3.7	64 ± 3.1	63 ± 3.3	63 ± 3.2	63 ± 3.3	63 ± 3.7
				Bark			
5.0-10.9	62 ± 1.9	--	--	68 ± 1.1	65 ± 2.9	67 ± 1.1	58 ± 2.4
≥11.0	64 ± 1.7	68 ± 1.5	68 ± 2.4	69 ± 1.5	66 ± 1.9	68 ± 1.5	60 ± 2.7
				Wood and Bark			
5.0-10.9	60 ± 1.2	--	--	61 ± 2.3	64 ± 1.2	62 ± 2.1	58 ± 2.3
≥11.0	63 ± 2.8	64 ± 3.3	65 ± 2.6	64 ± 2.9	63 ± 2.6	64 ± 2.8	62 ± 3.4
				BLACK LOCUST			
				Wood			
5.0-10.9	59 ± 4.5	--	--	59 ± 5.5	58 ± 4.5	59 ± 5.1	58 ± 2.2
≥11.0	60 ± 2.9	60 ± 3.2	60 ± 3.6	60 ± 2.9	62 ± 4.3	60 ± 2.9	60 ± 2.7
				Bark			
5.0-10.9	30 ± 3.2	--	--	29 ± 4.0	33 ± 3.5	29 ± 3.8	34 ± 4.8
≥11.0	29 ± 2.5	28 ± 2.4	30 ± 3.0	28 ± 2.6	34 ± 2.4	28 ± 2.6	33 ± 2.7
				Wood and Bark			
5.0-10.9	51 ± 3.7	--	--	52 ± 4.9	51 ± 3.4	52 ± 4.6	49 ± 2.4
≥11.0	52 ± 2.4	52 ± 2.7	52 ± 2.9	52 ± 2.5	52 ± 3.8	52 ± 2.5	49 ± 2.3
				HICKORY			
				Wood			
5.0-10.9	67 ± 6.7	--	--	68 ± 7.0	74 ± 18.8	68 ± 7.9	59 ± 4.6
≥11.0	62 ± 2.0	63 ± 2.7	65 ± 5.0	63 ± 2.3	63 ± 7.0	63 ± 2.3	60 ± 2.7
				Bark			
5.0-10.9	53 ± 2.1	--	--	54 ± 1.7	55 ± 2.9	54 ± 1.7	52 ± 4.6
≥11.0	56 ± 1.9	57 ± 2.1	57 ± 2.1	57 ± 2.0	57 ± 3.0	57 ± 2.0	54 ± 3.0
				Wood and Bark			
5.0-10.9	64 ± 5.3	--	--	65 ± 5.9	68 ± 13.2	66 ± 6.5	56 ± 3.7
≥11.0	61 ± 1.8	62 ± 2.4	63 ± 3.9	62 ± 2.1	61 ± 5.2	62 ± 2.0	58 ± 2.2

Continued

Table 5.--Average green weight per cubic foot of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Southern Appalachian Mountains--Continued

Tree size class (inches)	Average and standard deviation						
		Stem					
	Total tree	Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	Branches
	Pounds per cubic foot						
BLACK OAK							
Wood							
5.0-10.9	62 ± 3.1	--	--	62 ± 3.7	62 ± 3.3	62 ± 3.3	63 ± 2.1
≥11.0	63 ± 1.8	63 ± 2.1	65 ± 3.4	63 ± 2.2	57 ± 4.5	63 ± 2.1	64 ± 1.6
Bark							
5.0-10.9	56 ± 3.0	--	--	56 ± 3.5	58 ± 3.4	56 ± 3.4	54 ± 5.3
≥11.0	57 ± 2.6	57 ± 2.9	58 ± 2.8	57 ± 2.8	59 ± 3.3	57 ± 2.7	57 ± 3.5
Wood and Bark							
5.0-10.9	61 ± 2.7	--	--	61 ± 3.2	61 ± 2.5	61 ± 2.9	60 ± 2.5
≥11.0	62 ± 1.7	62 ± 2.1	64 ± 3.0	62 ± 2.1	58 ± 3.4	62 ± 2.0	62 ± 1.6
CHESTNUT OAK							
Wood							
5.0-10.9	62 ± 4.0	--	--	63 ± 5.0	60 ± 3.9	63 ± 4.3	61 ± 2.0
≥11.0	64 ± 2.4	65 ± 2.5	62 ± 3.7	65 ± 2.6	57 ± 3.9	64 ± 2.6	63 ± 3.0
Bark							
5.0-10.9	48 ± 5.2	--	--	47 ± 5.3	47 ± 4.9	47 ± 5.2	50 ± 4.9
≥11.0	50 ± 3.7	51 ± 4.0	49 ± 3.9	51 ± 4.0	50 ± 3.8	51 ± 3.9	50 ± 3.9
Wood and Bark							
5.0-10.9	59 ± 4.2	--	--	59 ± 5.1	56 ± 3.4	59 ± 4.5	57 ± 2.7
≥11.0	61 ± 2.6	62 ± 2.7	58 ± 3.4	62 ± 2.7	55 ± 3.1	62 ± 2.7	58 ± 3.2
NORTHERN RED OAK							
Wood							
5.0-10.9	65 ± 1.9	--	--	65 ± 1.8	61 ± 2.7	65 ± 2.0	63 ± 2.2
≥11.0	65 ± 1.2	66 ± 1.5	66 ± 1.8	66 ± 1.5	62 ± 1.6	66 ± 1.5	64 ± 1.8
Bark							
5.0-10.9	63 ± 2.0	--	--	64 ± 2.1	63 ± 3.2	64 ± 2.2	60 ± 2.4
≥11.0	62 ± 1.9	63 ± 2.5	64 ± 2.2	63 ± 2.4	62 ± 2.0	63 ± 2.4	61 ± 2.8
Wood and Bark							
5.0-10.9	64 ± 1.7	--	--	65 ± 1.6	61 ± 2.5	65 ± 1.8	62 ± 2.0
≥11.0	65 ± 1.1	65 ± 1.5	65 ± 1.7	65 ± 1.4	62 ± 1.3	65 ± 1.4	63 ± 1.7

Continued

Table 5.--Average green weight per cubic foot of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Southern Appalachian Mountains--Continued

Tree size class (inches)	Average and standard deviation						
		Stem					
	Total tree	Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	Branches
	Pounds per cubic foot						
SCARLET OAK							
				Wood			
5.0-10.9	65 ± 1.8	--	--	66 ± 2.4	62 ± 1.9	65 ± 2.1	63 ± 1.7
≥11.0	65 ± 1.5	64 ± 1.7	67 ± 3.5	65 ± 1.7	61 ± 2.8	64 ± 1.7	65 ± 2.0
				Bark			
5.0-10.9	58 ± 2.3	--	--	60 ± 2.0	59 ± 2.9	60 ± 1.8	54 ± 4.2
≥11.0	62 ± 2.5	63 ± 2.3	64 ± 2.0	63 ± 2.2	60 ± 2.7	63 ± 2.2	60 ± 3.4
				Wood and Bark			
5.0-10.9	63 ± 1.8	--	--	65 ± 2.3	61 ± 1.8	64 ± 2.0	60 ± 1.9
≥11.0	64 ± 1.3	64 ± 1.4	67 ± 3.1	64 ± 1.5	61 ± 2.3	64 ± 1.4	63 ± 1.7
WHITE OAK							
				Wood			
5.0-10.9	65 ± 1.8	--	--	65 ± 2.2	63 ± 2.3	65 ± 1.9	63 ± 2.3
≥11.0	65 ± 1.7	65 ± 1.7	64 ± 5.6	65 ± 1.6	61 ± 3.1	65 ± 1.6	65 ± 2.8
				Bark			
5.0-10.9	51 ± 3.3	--	--	50 ± 3.7	52 ± 3.2	50 ± 3.6	53 ± 2.5
≥11.0	56 ± 2.7	56 ± 3.9	57 ± 2.7	56 ± 3.6	57 ± 2.1	56 ± 3.5	55 ± 2.8
				Wood and Bark			
5.0-10.9	62 ± 1.7	--	--	63 ± 2.0	60 ± 2.2	63 ± 1.8	60 ± 2.2
≥11.0	63 ± 1.7	64 ± 1.5	62 ± 4.5	64 ± 1.6	60 ± 2.4	64 ± 1.6	62 ± 2.5
ALL SPECIES							
				Wood			
5.0-10.9	60 ± 6.6	--	--	60 ± 6.9	60 ± 9.4	60 ± 6.9	58 ± 5.7
≥11.0	60 ± 6.0	61 ± 5.9	62 ± 6.2	60 ± 6.3	60 ± 7.5	60 ± 6.2	61 ± 5.2
				Bark			
5.0-10.9	53 ± 8.5	--	--	53 ± 10.0	55 ± 8.2	53 ± 9.7	54 ± 6.7
≥11.0	53 ± 8.6	54 ± 9.7	55 ± 9.4	53 ± 9.9	55 ± 7.2	53 ± 9.9	55 ± 7.1
				Wood and Bark			
5.0-10.9	58 ± 6.0	--	--	59 ± 6.5	58 ± 7.5	59 ± 6.5	57 ± 4.6
≥11.0	59 ± 6.0	60 ± 6.0	60 ± 6.3	59 ± 6.5	58 ± 5.5	59 ± 6.4	59 ± 4.9

Table 6.--Average green weight of wood and bark per cubic foot of wood, by tree component and size class, for hardwood species in the Southern Appalachian Mountains

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Pounds per cubic foot						
SOFT HARDWOODS							
5.0-10.9	68 ± 7.5	--	--	66 ± 7.2	69 ± 9.1	66 ± 7.3	81 ± 8.3
≥11.0	65 ± 5.5	63 ± 5.4	68 ± 6.4	62 ± 5.1	73 ± 8.4	63 ± 5.1	82 ± 6.6
BASSWOOD							
5.0-10.9	66 ± 1.5	--	--	65 ± 2.3	63 ± 3.3	65 ± 2.2	78 ± 7.6
≥11.0	61 ± 4.5	58 ± 5.1	60 ± 2.6	58 ± 4.6	64 ± 3.3	58 ± 4.6	75 ± 6.9
BLACKGUM							
5.0-10.9	81 ± 4.0	--	--	78 ± 5.0	82 ± 1.9	78 ± 4.9	92 ± 4.0
≥11.0	73 ± 4.6	70 ± 4.6	71 ± 1.7	70 ± 4.2	81 ± 2.4	70 ± 4.1	86 ± 5.5
RED MAPLE							
5.0-10.9	69 ± 4.1	--	--	67 ± 4.2	68 ± 5.0	67 ± 4.3	78 ± 9.6
≥11.0	67 ± 3.4	64 ± 3.3	66 ± 4.5	64 ± 3.1	69 ± 4.0	64 ± 3.1	77 ± 3.1
YELLOW-POPLAR							
5.0-10.9	63 ± 5.6	--	--	61 ± 5.2	67 ± 10.0	62 ± 5.6	81 ± 4.4
≥11.0	63 ± 4.3	61 ± 2.9	72 ± 6.3	61 ± 4.0	75 ± 8.5	61 ± 4.1	83 ± 5.8
HARD HARDWOODS							
5.0-10.9	75 ± 7.3	--	--	73 ± 7.5	78 ± 7.6	74 ± 7.8	85 ± 7.1
≥11.0	75 ± 5.8	72 ± 5.9	77 ± 6.7	72 ± 5.7	82 ± 9.0	73 ± 5.7	85 ± 6.7
WHITE ASH							
5.0-10.9	65 ± 4.0	--	--	62 ± 3.7	72 ± 6.2	63 ± 4.0	77 ± 5.4
≥11.0	63 ± 3.9	59 ± 3.8	67 ± 6.8	60 ± 3.8	82 ± 9.5	60 ± 3.8	75 ± 6.0
SWEET BIRCH							
5.0-10.9	74 ± 2.2	--	--	69 ± 2.5	78 ± 1.3	70 ± 2.5	86 ± 6.0
≥11.0	77 ± 3.4	73 ± 4.1	77 ± 3.4	73 ± 3.6	80 ± 4.1	73 ± 3.5	88 ± 6.3
BLACK LOCUST							
5.0-10.9	70 ± 3.3	--	--	68 ± 4.2	71 ± 3.0	69 ± 3.8	78 ± 4.5
≥11.0	70 ± 2.6	68 ± 3.4	71 ± 4.1	69 ± 2.8	82 ± 4.3	69 ± 2.8	79 ± 4.6
HICKORY							
5.0-10.9	83 ± 8.0	--	--	81 ± 7.4	87 ± 10.5	82 ± 9.1	86 ± 5.6
≥11.0	76 ± 2.9	73 ± 2.7	78 ± 6.5	73 ± 2.5	91 ± 8.1	73 ± 2.5	86 ± 5.7

Continued

Table 6.--Average green weight of wood and bark per cubic foot of wood, by tree component and size class, for hardwood species in the Southern Appalachian Mountains

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Pounds per cubic foot						
BLACK OAK							
5.0-10.9	77 ± 2.5	--	--	75 ± 3.3	81 ± 3.6	76 ± 2.9	91 ± 4.5
≥11.0	77 ± 2.4	74 ± 2.3	80 ± 3.0	74 ± 2.2	79 ± 4.2	74 ± 2.1	88 ± 3.9
CHESTNUT OAK							
5.0-10.9	79 ± 5.0	--	--	78 ± 5.0	82 ± 5.8	78 ± 4.8	89 ± 9.0
≥11.0	80 ± 3.4	77 ± 2.8	81 ± 6.6	78 ± 3.1	86 ± 8.9	78 ± 3.1	91 ± 4.8
NORTHERN RED OAK							
5.0-10.9	77 ± 2.0	--	--	76 ± 2.0	75 ± 3.0	75 ± 2.0	83 ± 3.5
≥11.0	77 ± 1.8	75 ± 1.8	78 ± 3.2	75 ± 1.8	72 ± 1.6	75 ± 1.8	84 ± 3.0
SCARLET OAK							
5.0-10.9	81 ± 2.5	--	--	78 ± 2.6	79 ± 1.7	78 ± 2.2	90 ± 3.7
≥11.0	76 ± 1.9	73 ± 2.1	79 ± 3.5	74 ± 2.1	78 ± 3.4	74 ± 2.1	85 ± 3.7
WHITE OAK							
5.0-10.9	77 ± 3.4	--	--	74 ± 2.7	81 ± 3.3	75 ± 2.8	91 ± 3.8
≥11.0	78 ± 2.2	74 ± 1.9	78 ± 5.2	74 ± 1.8	88 ± 7.0	74 ± 1.8	88 ± 5.4
ALL SPECIES							
5.0-10.9	73 ± 8.0	--	--	71 ± 8.1	75 ± 9.0	72 ± 8.3	84 ± 7.6
≥11.0	73 ± 7.2	70 ± 6.8	75 ± 7.6	70 ± 7.1	80 ± 9.6	70 ± 7.1	84 ± 6.8

Table 7.--Regression equations for estimating green and dry weight of the above-stump total-tree wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. as the independent variable

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL-TREE WOOD AND BARK				
Soft Hardwoods	Green	3.55211	1.25948	4.02745	1.23329	0.98	0.0642	128
	Dry	1.56282	1.28807	1.88621	1.24885	0.97	0.0758	128
Basswood	Green	3.71029	1.24226	5.02472	1.17902	0.98	0.0552	18
	Dry	1.94274	1.21008	1.47600	1.26737	0.98	0.0630	18
Blackgum (upland)	Green	3.32017	1.25136	4.90406	1.17002	0.98	0.0619	18
	Dry	1.54160	1.27590	2.01627	1.21993	0.97	0.0679	18
Red maple	Green	4.02365	1.25353	10.63281	1.05091	0.98	0.0602	30
	Dry	2.02338	1.27612	5.28790	1.07581	0.98	0.0558	30
Yellow-poplar	Green	2.53157	1.33741	4.17992	1.23285	0.99	0.0581	62
	Dry	0.87948	1.40401	1.65215	1.27254	0.99	0.0568	62
Hard Hardwoods	Green	3.20171	1.30631	3.74095	1.27386	0.97	0.0794	347
	Dry	1.99067	1.30291	2.66968	1.24172	0.97	0.0738	347
White ash	Green	4.26515	1.21919	5.51740	1.16551	0.98	0.0617	52
	Dry	2.71163	1.22990	3.96491	1.15068	0.98	0.0633	52
Sweet birch	Green	7.26568	1.14114	6.22976	1.17321	0.99	0.0419	21
	Dry	4.29408	1.14203	3.80734	1.16711	0.99	0.0418	21
Black locust	Green	6.12062	1.08931	1.36924	1.40154	0.96	0.0780	18
	Dry	4.13741	1.08876	1.04649	1.37539	0.95	0.0831	18
Hickory	Green	1.37649	1.50566	4.68499	1.25027	0.99	0.0595	54
	Dry	0.93747	1.49389	3.30276	1.23130	0.98	0.0637	54
Black oak	Green	2.21828	1.36803	3.65717	1.26378	0.99	0.0556	27
	Dry	1.29270	1.36723	2.54650	1.22586	0.98	0.0607	27
Chestnut oak	Green	1.34863	1.48845	5.41481	1.19861	0.98	0.0690	51
	Dry	0.86674	1.47585	3.40602	1.19049	0.98	0.0667	51
North. red oak	Green	5.08421	1.23759	5.81355	1.20964	0.99	0.0452	71
	Dry	3.06739	1.22338	3.28071	1.20936	0.99	0.0488	71
Scarlet oak	Green	2.81706	1.34308	4.69089	1.23675	0.99	0.0444	27
	Dry	1.62952	1.34103	2.94915	1.21733	0.99	0.0481	27
White oak	Green	2.82506	1.34053	2.51286	1.36495	0.99	0.0566	28
	Dry	1.73738	1.33404	1.69511	1.33917	0.99	0.0594	28
All Species	Green	3.29754	1.29311	3.65829	1.27146	0.97	0.0790	475
	Dry	1.83051	1.30348	2.24309	1.26110	0.96	0.0948	475

Continued

Table 7.--Regression equations for estimating green and dry weight of the above-stump total-tree wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. as the independent variable--Continued

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL-TREE WOOD				
Soft Hardwoods	Green	2.65877	1.28067	3.26758	1.23767	0.98	0.0681	128
	Dry	1.20522	1.30165	1.45172	1.26285	0.97	0.0854	128
Basswood	Green	2.58221	1.26827	3.14665	1.22705	0.98	0.0551	18
	Dry	1.26050	1.24541	0.86609	1.32366	0.97	0.0670	18
Blackgum (upland)	Green	2.55358	1.26884	4.23002	1.16360	0.97	0.0724	18
	Dry	1.14382	1.28857	1.50453	1.23141	0.96	0.0888	18
Red maple	Green	3.05121	1.27840	9.88085	1.03339	0.97	0.0597	30
	Dry	1.45160	1.31226	5.01312	1.05382	0.98	0.0557	30
Yellow-poplar	Green	1.86103	1.36142	3.33413	1.23984	0.99	0.0592	62
	Dry	0.74862	1.40085	1.36501	1.27560	0.99	0.0585	62
Hard Hardwoods	Green	2.36129	1.33180	3.11979	1.27371	0.97	0.0834	347
	Dry	1.51263	1.32307	2.34759	1.23142	0.97	0.0790	347
White ash	Green	2.87027	1.26533	4.70464	1.16229	0.98	0.0612	52
	Dry	2.07306	1.25505	3.41692	1.15086	0.98	0.0637	52
Sweet birch	Green	5.91898	1.14179	4.85269	1.18321	0.98	0.0507	21
	Dry	3.66009	1.13191	3.11384	1.16562	0.98	0.0510	21
Black locust	Green	5.20919	1.08668	0.95293	1.44088	0.95	0.0864	18
	Dry	3.59150	1.08426	0.77942	1.40281	0.95	0.0855	18
Hickory	Green	0.97960	1.53720	3.93165	1.24743	0.98	0.0660	54
	Dry	0.69361	1.52150	2.90230	1.22305	0.98	0.0708	54
Black oak	Green	1.45544	1.41790	3.38847	1.24169	0.98	0.0590	27
	Dry	0.85607	1.41438	2.64971	1.17879	0.98	0.0660	27
Chestnut oak	Green	1.02336	1.49892	4.11244	1.20889	0.98	0.0693	51
	Dry	0.62578	1.49459	2.57329	1.19976	0.98	0.0688	51
North. red oak	Green	3.94331	1.25731	4.95616	1.20964	0.99	0.0463	71
	Dry	2.36123	1.24202	2.86474	1.20171	0.99	0.0499	71
Scarlet oak	Green	1.80365	1.39869	3.70487	1.24859	0.99	0.0443	27
	Dry	1.10326	1.38254	2.36997	1.22310	0.99	0.0497	27
White oak	Green	2.42774	1.33511	2.07560	1.36779	0.99	0.0578	28
	Dry	1.48789	1.33079	1.45208	1.33587	0.99	0.0617	28
All Species	Green	2.44274	1.31733	3.02592	1.27269	0.97	0.0829	475
	Dry	1.39612	1.32195	1.90236	1.25744	0.95	0.1003	475

[1]Trees < 11.0 inches d.b.h.

$Y = a'(D^2)^b$

[2]Trees ≥ 11.0 inches d.b.h.

$Y = a''(D^2)^b$

Where: Y = component weight in pounds
D = tree d.b.h. in inches
a', a", b = regression coefficients

[3]$\log_{10}$ form

Table 8.--Regression equations for estimating green and dry weight of the total-stem wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. as the independent variable

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL-STEM WOOD AND BARK				
Soft Hardwoods	Green	3.22563	1.23876	2.88886	1.26175	0.97	0.0785	128
	Dry	1.40805	1.27033	1.34203	1.28034	0.97	0.0801	128
Basswood	Green	3.34246	1.22154	5.22567	1.12836	0.98	0.0485	18
	Dry	1.74995	1.19103	1.49368	1.22405	0.98	0.0575	18
Blackgum (upland)	Green	1.64629	1.34504	3.43542	1.19165	0.97	0.0727	18
	Dry	0.77244	1.36853	1.40359	1.24400	0.97	0.0790	18
Red maple	Green	4.94211	1.14841	6.87118	1.07970	0.97	0.0679	30
	Dry	2.41282	1.17937	3.56511	1.09796	0.97	0.0631	30
Yellow-poplar	Green	2.18263	1.34804	4.43647	1.20013	0.98	0.0596	62
	Dry	0.76237	1.41643	1.76476	1.24142	0.99	0.0599	62
Hard Hardwoods	Green	3.09026	1.27061	4.67860	1.18413	0.97	0.0776	347
	Dry	1.93666	1.26546	3.53278	1.14011	0.97	0.0730	347
White ash	Green	4.84664	1.13887	3.97350	1.18029	0.97	0.0682	52
	Dry	3.12185	1.14771	2.84169	1.16732	0.97	0.0704	52
Sweet birch	Green	5.76494	1.12244	4.79623	1.16080	0.98	0.0521	21
	Dry	3.34713	1.27356	3.06473	1.14574	0.98	0.0511	21
Black locust	Green	5.82355	1.05973	0.89294	1.45073	0.94	0.0904	18
	Dry	4.06014	1.05285	0.72201	1.41295	0.94	0.0945	18
Hickory	Green	1.73761	1.41142	5.78715	1.16054	0.98	0.0576	54
	Dry	1.17992	1.40117	4.27343	1.13282	0.98	0.0614	54
Black oak	Green	2.14218	1.34513	7.56363	1.08208	0.99	0.0529	27
	Dry	1.27041	1.34023	5.90002	1.02003	0.98	0.0585	27
Chestnut oak	Green	1.38351	1.45567	8.16034	1.08563	0.98	0.0653	51
	Dry	0.89495	1.44204	5.38410	1.06787	0.98	0.0625	51
North. red oak	Green	5.08849	1.19370	6.64281	1.13812	0.99	0.0452	71
	Dry	3.11987	1.17348	3.82608	1.13093	0.99	0.0467	71
Scarlet oak	Green	1.54710	1.42294	6.43469	1.12574	0.99	0.0471	27
	Dry	0.90818	1.41531	4.32971	1.08964	0.99	0.0507	27
White oak	Green	2.54174	1.32196	4.71951	1.19292	0.98	0.0646	28
	Dry	1.59285	1.31179	3.42725	1.15202	0.98	0.0682	28
All Species	Green	3.11290	1.26260	4.03992	1.20824	0.97	0.0790	475
	Dry	1.73051	1.27261	2.58728	1.18874	0.96	0.0895	475

Continued

Table 8.--Regression equations for estimating green and dry weight of the total-stem wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. as the independent variable--Continued

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL-STEM WOOD				
Soft Hardwoods	Green	2.46606	1.26259	2.51860	1.25819	0.97	0.0793	128
	Dry	1.06273	1.29440	1.10764	1.28577	0.96	0.0894	128
Basswood	Green	2.30938	1.25892	3.31591	1.18348	0.98	0.0514	18
	Dry	1.12481	1.23786	0.90690	1.28276	0.98	0.0635	18
Blackgum (upland)	Green	1.24921	1.37279	3.29438	1.17059	0.97	0.0820	18
	Dry	0.55552	1.39637	1.18172	1.23898	0.95	0.0981	18
Red maple	Green	3.54641	1.19449	6.97484	1.05346	0.97	0.0659	30
	Dry	1.62534	1.23722	3.67497	1.06711	0.97	0.0619	30
Yellow-poplar	Green	1.80879	1.35110	3.57285	1.20916	0.98	0.0607	62
	Dry	0.66009	1.41104	1.43045	1.24978	0.99	0.0609	62
Hard Hardwoods	Green	2.28723	1.30180	3.88139	1.19153	0.97	0.0813	347
	Dry	1.46631	1.29169	3.05149	1.13887	0.97	0.0778	347
White ash	Green	3.25897	1.19382	3.63629	1.17098	0.97	0.0686	52
	Dry	2.37705	1.18055	2.58557	1.16301	0.97	0.0697	52
Sweet birch	Green	5.03040	1.12103	4.30529	1.15349	0.98	0.0588	21
	Dry	2.97489	1.11933	2.78946	1.13275	0.98	0.0587	21
Black locust	Green	4.83873	1.06808	0.70544	1.46959	0.94	0.0955	18
	Dry	3.41664	1.06056	0.60942	1.42002	0.94	0.0948	18
Hickory	Green	1.17748	1.46100	4.78689	1.16855	0.98	0.0648	54
	Dry	0.83461	1.44423	3.67039	1.13540	0.98	0.0684	54
Black oak	Green	1.41717	1.39770	6.43849	1.08208	0.98	0.0569	27
	Dry	0.83649	1.39137	5.50646	0.99842	0.98	0.0642	27
Chestnut oak	Green	1.02865	1.47458	5.78444	1.11449	0.98	0.0678	51
	Dry	0.63137	1.46903	3.73598	1.09831	0.98	0.0664	51
North. red oak	Green	3.95586	1.21777	5.61591	1.14470	0.99	0.0462	71
	Dry	2.40772	1.19591	3.27347	1.13186	0.99	0.0481	71
Scarlet oak	Green	1.06906	1.46877	5.10270	1.14286	0.99	0.0484	27
	Dry	0.63385	1.45552	3.45720	1.10180	0.99	0.0526	27
White oak	Green	2.22827	1.31979	3.83790	1.20642	0.98	0.0660	28
	Dry	1.38070	1.31206	2.87565	1.15907	0.98	0.0707	28
All Species	Green	2.32825	1.29142	3.38635	1.21330	0.97	0.0819	475
	Dry	1.30842	1.29844	2.20176	1.18992	0.95	0.0959	475

[1]Trees < 11.0 inches d.b.h.

$Y = a'(D^2)^b$

[2]Trees $\geq$ 11.0 inches d.b.h.

$Y = a''(D^2)^b$

Where: Y = component weight in pounds
D = tree d.b.h. in inches
a', a", b = regression coefficients

[3]$\log_{10}$ form

Table 9.--Regression equations for estimating cubic-foot volume of the above-stump total-tree wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. as the independent variable

Species or species group	Volume wood & bark or wood only	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL TREE				
Soft Hardwoods	Wd&Bk	0.05802	1.28608	0.06153	1.27383	0.98	0.0663	128
	Wood	0.04501	1.29710	0.05131	1.26978	0.97	0.0734	128
Basswood	Wd&Bk	0.07357	1.23831	0.06447	1.26584	0.98	0.0569	18
	Wood	0.04976	1.27105	0.03994	1.31689	0.98	0.0554	18
Blackgum (upland)	Wd&Bk	0.04090	1.31863	0.06364	1.22644	0.99	0.0455	18
	Wood	0.02912	1.33350	0.04119	1.26120	0.99	0.0510	18
Red maple	Wd&Bk	0.06378	1.27295	0.15680	1.08537	0.98	0.0557	30
	Wood	0.04930	1.29431	0.14248	1.07299	0.98	0.0579	30
Yellow-poplar	Wd&Bk	0.04585	1.35223	0.07795	1.24157	0.99	0.0541	62
	Wood	0.03886	1.34410	0.06532	1.23584	0.99	0.0555	62
Hard Hardwoods	Wd&Bk	0.05537	1.29983	0.07301	1.24217	0.98	0.0655	347
	Wood	0.03915	1.32732	0.05585	1.25324	0.97	0.0753	347
White ash	Wd&Bk	0.08067	1.22543	0.09913	1.18248	0.98	0.0580	52
	Wood	0.05529	1.26044	0.07580	1.19466	0.98	0.0600	52
Sweet birch	Wd&Bk	0.11822	1.14568	0.15666	1.08698	0.99	0.0380	21
	Wood	0.09520	1.15088	0.13160	1.08336	0.99	0.0446	21
Black locust	Wd&Bk	0.10831	1.11241	0.03519	1.34682	0.96	0.0762	18
	Wood	0.07412	1.12961	0.02836	1.32995	0.96	0.0783	18
Hickory	Wd&Bk	0.02021	1.52367	0.06722	1.27307	0.98	0.0613	54
	Wood	0.01280	1.57260	0.05106	1.28412	0.98	0.0674	54
Black oak	Wd&Bk	0.04099	1.33969	0.05912	1.26330	0.99	0.0536	27
	Wood	0.02595	1.39254	0.05279	1.24450	0.99	0.0552	27
Chestnut oak	Wd&Bk	0.02622	1.45566	0.09785	1.18104	0.98	0.0611	51
	Wood	0.01764	1.47986	0.06883	1.19592	0.98	0.0619	51
North. red oak	Wd&Bk	0.08970	1.20851	0.08773	1.21314	0.99	0.0442	71
	Wood	0.07073	1.22312	0.07400	1.21369	0.99	0.0449	71
Scarlet oak	Wd&Bk	0.04951	1.31646	0.06803	1.25020	0.99	0.0453	27
	Wood	0.03011	1.37901	0.04966	1.27467	0.99	0.0432	27
White oak	Wd&Bk	0.04304	1.35273	0.04598	1.33897	0.99	0.0513	28
	Wood	0.03430	1.35552	0.03445	1.35460	0.99	0.0522	28
All Species	Wd&Bk	0.05612	1.29589	0.06974	1.25058	0.98	0.0656	475
	Wood	0.04091	1.31780	0.05462	1.25751	0.97	0.0746	475

[1]Trees < 11.0 inches d.b.h.

$$Y = a'(D^2)^b$$

[2]Trees $\geq$ 11.0 inches d.b.h.

$$Y = a''(D^2)^b$$

Where: Y = component volume in cubic feet
D = tree d.b.h. in inches
a', a", b = regression coefficients

[3]$\log_{10}$ form

Table 10.--Regression equations for estimating cubic-foot volume of the total-stem wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. as the independent variable

Species or species group	Volume wood & bark or wood only	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL STEM				
Soft Hardwoods	Wd&Bk	0.05195	1.26995	0.04238	1.31240	0.96	0.0903	128
	Wood	0.03947	1.29199	0.03836	1.29797	0.96	0.0933	128
Basswood	Wd&Bk	0.06238	1.23003	0.06487	1.22188	0.99	0.0446	18
	Wood	0.04157	1.27449	0.04134	1.27562	0.99	0.0460	18
Blackgum (upland)	Wd&Bk	0.02124	1.40349	0.04354	1.25385	0.98	0.0628	18
	Wood	0.01380	1.44717	0.03267	1.26743	0.98	0.0660	18
Red maple	Wd&Bk	0.07559	1.17514	0.09946	1.11791	0.97	0.0663	30
	Wood	0.05485	1.21982	0.10109	1.09235	0.97	0.0666	30
Yellow-poplar	Wd&Bk	0.03888	1.36861	0.08087	1.21590	0.98	0.0597	62
	Wood	0.03438	1.35427	0.06773	1.21287	0.98	0.0597	62
Hard Hardwoods	Wd&Bk	0.05337	1.26301	0.09024	1.15347	0.98	0.0672	347
	Wood	0.03738	1.29966	0.06889	1.17215	0.97	0.0741	347
White ash	Wd&Bk	0.09402	1.14061	0.06737	1.21012	0.97	0.0750	52
	Wood	0.06326	1.18725	0.05445	1.21852	0.97	0.0758	52
Sweet birch	Wd&Bk	0.08453	1.14744	0.12361	1.06818	0.98	0.0474	21
	Wood	0.07232	1.15397	0.12089	1.04683	0.98	0.0520	21
Black locust	Wd&Bk	0.10288	1.08093	0.02191	1.40339	0.94	0.0948	18
	Wood	0.06691	1.11710	0.02106	1.35819	0.94	0.0913	18
Hickory	Wd&Bk	0.02510	1.42907	0.08166	1.18313	0.98	0.0598	54
	Wood	0.01480	1.50277	0.06279	1.20138	0.98	0.0667	54
Black oak	Wd&Bk	0.04054	1.31045	0.11881	1.08626	0.99	0.0509	27
	Wood	0.02568	1.36870	0.09878	1.08776	0.99	0.0529	27
Chestnut oak	Wd&Bk	0.02746	1.47145	0.19753	1.06004	0.98	0.0602	51
	Wood	0.01793	1.45245	0.09736	1.09965	0.98	0.0617	51
North. red oak	Wd&Bk	0.09105	1.15950	0.09673	1.14688	0.99	0.0451	71
	Wood	0.07170	1.17986	0.08156	1.15300	0.99	0.0456	71
Scarlet oak	Wd&Bk	0.02603	1.40341	0.08946	1.14595	0.99	0.0465	27
	Wood	0.01730	1.45519	0.06724	1.17208	0.99	0.0465	27
White oak	Wd&Bk	0.03821	1.33563	0.08641	1.16549	0.98	0.0602	28
	Wood	0.03097	1.34368	0.06420	1.19163	0.98	0.0607	28
All Species	Wd&Bk	0.05279	1.26592	0.07606	1.18976	0.97	0.0760	475
	Wood	0.03798	1.29756	0.06054	1.20033	0.97	0.0810	475

[1]Trees < 11.0 inches d.b.h.

$Y = a'(D^2)^b$

[2]Trees $\geq$ 11.0 inches d.b.h.

$Y = a''(D^2)^b$

Where: Y = component volume in cubic feet
D = tree d.b.h. in inches
a', a", b = regression coefficients

[3]$\log_{10}$ form

Table 11.--Regression equations for estimating green and dry weight of the above-stump total-tree wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. and total height as the independent variables

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL-TREE WOOD AND BARK					
Soft Hardwoods	Green	0.31602	0.91874	0.20742	1.00653	0.91874	0.97	0.0707	128
	Dry	0.16021	0.91717	0.08941	1.03878	0.91717	0.96	0.0936	128
Basswood	Green	0.09136	1.05036	0.14541	0.95344	1.05036	0.98	0.0505	18
	Dry	0.05335	1.02167	0.04667	1.04954	1.02167	0.98	0.0603	18
Blackgum (upland)	Green	0.47487	0.88913	0.36480	0.94411	0.88913	0.98	0.0601	18
	Dry	0.20398	0.91126	0.14438	0.98332	0.91126	0.98	0.0621	18
Red maple	Green	0.16008	1.01323	0.34839	0.85107	1.01323	0.98	0.0544	30
	Dry	0.07954	1.02615	0.16035	0.87996	1.02615	0.98	0.0547	30
Yellow-poplar	Green	0.19596	0.96111	0.13363	1.04093	0.96111	0.99	0.0550	62
	Dry	0.05841	1.01185	0.04445	1.06881	1.01185	0.99	0.0506	62
Hard Hardwoods	Green	0.19669	0.98801	0.11131	1.10671	0.98801	0.98	0.0702	347
	Dry	0.12092	0.98756	0.08018	1.07324	0.98756	0.98	0.0625	347
White ash	Green	0.21956	0.96160	0.24471	0.93899	0.96160	0.97	0.0654	52
	Dry	0.15213	0.96987	0.19074	0.92271	0.96987	0.97	0.0673	52
Sweet birch	Green	0.44356	0.90980	0.20032	1.07555	0.90980	0.99	0.0358	21
	Dry	0.26925	0.90717	0.12181	1.07256	0.90717	0.99	0.0389	21
Black locust	Green	0.63183	0.82875	0.14351	1.13781	0.82875	0.97	0.0658	18
	Dry	0.41824	0.83091	0.11081	1.10786	0.83091	0.97	0.0703	18
Hickory	Green	0.06729	1.11301	0.09083	1.05044	1.11301	0.99	0.0493	54
	Dry	0.04484	1.10947	0.06609	1.02860	1.10947	0.99	0.0497	54
Black oak	Green	0.15621	1.00554	0.06290	1.19522	1.00554	0.99	0.0436	27
	Dry	0.09126	1.00484	0.04390	1.15741	1.00484	0.99	0.0500	27
Chestnut oak	Green	0.12392	1.03751	0.09386	1.09544	1.03751	0.98	0.0598	51
	Dry	0.08257	1.02692	0.06110	1.08969	1.02692	0.99	0.0591	51
North. red oak	Green	0.23662	0.97831	0.17965	1.03575	0.97831	0.99	0.0395	71
	Dry	0.14824	0.96680	0.10553	1.03766	0.96680	0.99	0.0439	71
Scarlet oak	Green	0.26569	0.97104	0.21019	1.01990	0.97104	0.99	0.0396	27
	Dry	0.15176	0.97144	0.13286	0.99918	0.97144	0.99	0.0419	27
White oak	Green	0.24482	0.96607	0.08487	1.18696	0.96607	0.99	0.0420	28
	Dry	0.14990	0.96325	0.05823	1.16040	0.96325	0.99	0.0437	28
All Species	Green	0.25451	0.95414	0.12346	1.10498	0.95414	0.97	0.0797	475
	Dry	0.15774	0.94683	0.07345	1.10620	0.94683	0.95	0.1017	475

Continued

Table 11.--Regression equations for estimating green and dry weight of the above-stump total-tree wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. and total height as the independent variables--Continued

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL-TREE WOOD					
Soft Hardwoods	Green	0.23311	0.93122	0.15977	1.00999	0.93122	0.97	0.0763	128
	Dry	0.11091	0.93642	0.06709	1.04123	0.93642	0.96	0.0974	128
Basswood	Green	0.06023	1.06970	0.08407	1.00015	1.06970	0.98	0.0527	18
	Dry	0.03219	1.04781	0.02456	1.10418	1.04781	0.97	0.0669	18
Blackgum (upland)	Green	0.33390	0.90895	0.30966	0.92466	0.90895	0.98	0.0647	18
	Dry	0.13582	0.93072	0.10799	0.97855	0.93072	0.98	0.0773	18
Red maple	Green	0.11327	1.03393	0.30305	0.82873	1.03393	0.98	0.0529	30
	Dry	0.05210	1.05514	0.13766	0.85253	1.05514	0.98	0.0546	30
Yellow-poplar	Green	0.13651	0.97924	0.10017	1.04379	0.97924	0.99	0.0553	62
	Dry	0.04912	1.01161	0.03699	1.07073	1.01161	0.99	0.0508	62
Hard Hardwoods	Green	0.13063	1.01304	0.08669	1.09853	1.01304	0.98	0.0710	347
	Dry	0.08244	1.01028	0.06680	1.05416	1.01028	0.98	0.0636	347
White ash	Green	0.12941	1.00033	0.18612	0.92456	1.00033	0.98	0.0636	52
	Dry	0.09735	0.99043	0.13839	0.91706	0.99043	0.97	0.0671	52
Sweet birch	Green	0.32861	0.92113	0.15693	1.07523	0.92113	0.99	0.0358	21
	Dry	0.21468	0.90970	0.10348	1.06186	0.90970	0.99	0.0400	21
Black locust	Green	0.51442	0.83256	0.10250	1.16894	0.83256	0.96	0.0722	18
	Dry	0.36413	0.82824	0.08353	1.13523	0.82824	0.96	0.0727	18
Hickory	Green	0.04243	1.14287	0.07024	1.03779	1.14287	0.99	0.0506	54
	Dry	0.02982	1.13570	0.05406	1.01167	1.13570	0.99	0.0530	54
Black oak	Green	0.09092	1.04481	0.05014	1.16891	1.04481	0.99	0.0447	27
	Dry	0.99231	1.04328	0.99230	1.16891	1.04328	0.99	0.0530	27
Chestnut oak	Green	0.09113	1.04647	0.06928	1.10364	1.04647	0.99	0.0585	51
	Dry	0.05684	1.04198	0.04387	1.09602	1.04198	0.99	0.0594	51
North. red oak	Green	0.17312	0.99498	0.14480	1.03223	0.99498	0.99	0.0397	71
	Dry	0.10808	0.98245	0.08739	1.02675	0.98245	0.99	0.0443	71
Scarlet oak	Green	0.15089	1.01381	0.14609	1.02054	1.01381	0.99	0.0361	27
	Dry	0.09311	1.00441	0.09709	0.99569	1.00441	0.99	0.0404	27
White oak	Green	0.20358	0.96705	0.07117	1.18619	0.96705	0.99	0.0377	28
	Dry	0.12347	0.96604	0.05037	1.15300	0.96604	0.99	0.0411	28
All Species	Green	0.17494	0.97508	0.09590	1.10044	0.97508	0.97	0.0821	475
	Dry	0.10805	0.96858	0.05945	1.09315	0.96858	0.95	0.1042	475

[1]Trees < 11.0 inches d.b.h.

$$Y = a'(D^2Th)^b$$

[2]Trees ≥ 11.0 inches d.b.h.

$$Y = a''(D^2)^b (Th)^c$$

Where: Y = component weight in pounds
D = tree d.b.h. in inches
Th = tree total height in feet
a', a", b, c = regression coefficients

[3]$\log_{10}$ form

Table 13.--Regression equations for estimating cubic-foot volume of the above-stump total-tree wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. and total height as the independent variables

Species or species group	Volume wood & bark or wood only	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL TREE					
Soft Hardwoods	Wd&Bk	0.00377	0.96802	0.00304	1.01320	0.96802	0.99	0.0494	128
	Wood	0.00269	0.98343	0.00248	0.99998	0.98343	0.99	0.0518	128
Basswood	Wd&Bk	0.00182	1.04757	0.00189	1.04029	1.04757	0.98	0.0520	18
	Wood	0.00113	1.07381	0.00106	1.08723	1.07381	0.98	0.0513	18
Blackgum (upland)	Wd&Bk	0.00558	0.93016	0.00404	0.99741	0.93016	0.99	0.0507	18
	Wood	0.00364	0.94820	0.00259	1.01950	0.94820	0.99	0.0476	18
Red maple	Wd&Bk	0.00240	1.02973	0.00488	0.88130	1.02973	0.98	0.0482	30
	Wood	0.00171	1.05004	0.00423	0.86117	1.05004	0.99	0.0471	30
Yellow-poplar	Wd&Bk	0.00311	0.98332	0.00239	1.03846	0.98332	0.99	0.0391	62
	Wood	0.00267	0.97804	0.00204	1.03346	0.97804	0.99	0.0405	62
Hard Hardwoods	Wd&Bk	0.00351	0.98106	0.00221	1.07756	0.98106	0.98	0.0556	347
	Wood	0.00216	1.01097	0.00157	1.07753	1.01097	0.98	0.0606	347
White ash	Wd&Bk	0.00389	0.97227	0.00437	0.94831	0.97227	0.98	0.0578	52
	Wood	0.00240	1.00222	0.00306	0.95133	1.00222	0.98	0.0581	52
Sweet birch	Wd&Bk	0.00754	0.90703	0.00495	0.99501	0.90703	0.99	0.0378	21
	Wood	0.00547	0.92188	0.00412	0.98078	0.92188	0.99	0.0344	21
Black locust	Wd&Bk	0.01034	0.84979	0.00356	1.07222	0.84979	0.97	0.0606	18
	Wood	0.00665	0.86588	0.00280	1.04662	0.86588	0.97	0.0604	18
Hickory	Wd&Bk	0.00102	1.11877	0.00124	1.07735	1.11877	0.99	0.0579	54
	Wood	0.00056	1.16061	0.00083	1.07704	1.16061	0.99	0.0593	54
Black oak	Wd&Bk	0.00318	0.97999	0.00111	1.19925	0.97999	0.99	0.0455	27
	Wood	0.00179	1.02067	0.00085	1.17661	1.02067	0.99	0.0451	27
Chestnut oak	Wd&Bk	0.00266	1.00944	0.00185	1.08446	1.00944	0.99	0.0562	51
	Wood	0.00168	1.02897	0.00122	1.09546	1.02897	0.99	0.0542	51
North. red oak	Wd&Bk	0.00448	0.95561	0.00294	1.04314	0.95561	0.99	0.0384	71
	Wood	0.00336	0.96872	0.00238	1.04053	0.96872	0.99	0.0379	71
Scarlet oak	Wd&Bk	0.00494	0.95073	0.00324	1.03857	0.95073	0.99	0.0418	27
	Wood	0.00264	0.99805	0.00205	1.05112	0.99805	0.99	0.0368	27
White oak	Wd&Bk	0.00371	0.97305	0.00150	1.16096	0.97305	0.99	0.0366	28
	Wood	0.00284	0.97894	0.00112	1.17278	0.97894	0.99	0.0321	28
All Species	Wd&Bk	0.00375	0.97203	0.00234	1.07007	0.97203	0.98	0.0557	475
	Wood	0.00242	0.99723	0.00174	1.06639	0.99723	0.98	0.0599	475

[1]Trees < 11.0 inches d.b.h.

$$Y = a'(D^2Th)^b$$

[2]Trees ≥ 11.0 inches d.b.h.

$$Y = a''(D^2)^b(Th)^c$$

Where: Y = component volume in cubic feet
D = tree d.b.h. in inches
Th = tree total height in feet
a', a", b, c = regression coefficients

[3]$\log_{10}$ form

Table 14.--Regression equations for estimating cubic-foot volume of the total-stem wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. and total height as the independent variables

Species or species group	Volume wood & bark or wood only	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL STEM					
Soft Hardwoods	Wd&Bk	0.00232	1.00250	0.00224	1.00966	1.00250	0.99	0.0403	128
	Wood	0.00166	1.02072	0.00193	0.98916	1.02072	0.99	0.0432	128
Basswood	Wd&Bk	0.00160	1.03943	0.00194	0.99928	1.03943	0.99	0.0395	18
	Wood	0.00094	1.07630	0.00109	1.04587	1.07630	0.99	0.0415	18
Blackgum (upland)	Wd&Bk	0.00201	1.01801	0.00250	0.97272	1.01801	0.99	0.0342	18
	Wood	0.00116	1.05448	0.00174	0.97115	1.05448	0.99	0.0283	18
Red maple	Wd&Bk	0.00313	0.96860	0.00427	0.90395	0.96860	0.99	0.0437	30
	Wood	0.00205	1.00321	0.00382	0.87340	1.00321	0.99	0.0446	30
Yellow-poplar	Wd&Bk	0.00235	1.00446	0.00237	1.00309	1.00446	0.99	0.0359	62
	Wood	0.00215	0.99360	0.00206	1.00256	0.99360	0.99	0.0369	62
Hard Hardwoods	Wd&Bk	0.00320	0.96878	0.00302	0.98064	0.96878	0.99	0.0465	347
	Wood	0.00196	1.00246	0.00209	0.98968	1.00246	0.99	0.0505	347
White ash	Wd&Bk	0.00432	0.93473	0.00386	0.95852	0.93473	0.98	0.0563	52
	Wood	0.00262	0.97061	0.00276	0.95927	0.97061	0.98	0.0574	52
Sweet birch	Wd&Bk	0.00446	0.93001	0.00394	0.95556	0.93001	0.99	0.0250	21
	Wood	0.00362	0.93932	0.00379	0.92974	0.93932	0.99	0.0276	21
Black locust	Wd&Bk	0.00935	0.83921	0.00248	1.11605	0.83921	0.96	0.0760	18
	Wood	0.00559	0.86772	0.00222	1.06058	0.86772	0.97	0.0697	18
Hickory	Wd&Bk	0.00144	1.05555	0.00193	0.99419	1.05555	0.99	0.0515	54
	Wood	0.00071	1.11439	0.00123	0.99890	1.11439	0.99	0.0548	54
Black oak	Wd&Bk	0.00311	0.96620	0.00242	1.01863	0.96620	0.99	0.0360	27
	Wood	0.00174	1.01004	0.00169	1.01653	1.01004	0.99	0.0362	27
Chestnut oak	Wd&Bk	0.00282	0.98847	0.00321	0.96142	0.98847	0.99	0.0501	51
	Wood	0.00173	1.01362	0.00186	0.99799	1.01362	0.99	0.0507	51
North. red oak	Wd&Bk	0.00463	0.92849	0.00370	0.97558	0.92849	0.99	0.0302	71
	Wood	0.00348	0.94423	0.00294	0.97909	0.94423	0.99	0.0308	71
Scarlet oak	Wd&Bk	0.00197	1.02777	0.00350	0.90801	1.02777	0.99	0.0241	27
	Wood	0.00119	1.06556	0.00233	0.92547	1.06556	0.99	0.0218	27
White oak	Wd&Bk	0.00307	0.97217	0.00296	0.97964	0.97217	0.99	0.0349	28
	Wood	0.00242	0.97936	0.00216	1.00348	0.97936	0.99	0.0335	28
All Species	Wd&Bk	0.00286	0.98063	0.00278	0.98659	0.98063	0.99	0.0453	475
	Wood	0.00186	1.00839	0.00204	0.98927	1.00839	0.99	0.0486	475

[1]Trees < 11.0 inches d.b.h.

$Y = a'(D^2Th)^b$

[2]Trees ≥ 11.0 inches d.b.h.

$Y = a''(D^2)^b(Th)^c$

Where: Y = component volume in cubic feet
D = tree d.b.h. in inches
Th = tree total height in feet
a', a", b, c = regression coefficients

[3]$\log_{10}$ form

Table 13.--Regression equations for estimating cubic-foot volume of the above-stump total-tree wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. and total height as the independent variables

Species or species group	Volume wood & bark or wood only	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL TREE					
Soft Hardwoods	Wd&Bk	0.00377	0.96802	0.00304	1.01320	0.96802	0.99	0.0494	128
	Wood	0.00269	0.98343	0.00248	0.99998	0.98343	0.99	0.0518	128
Basswood	Wd&Bk	0.00182	1.04757	0.00189	1.04029	1.04757	0.98	0.0520	18
	Wood	0.00113	1.07381	0.00106	1.08723	1.07381	0.98	0.0513	18
Blackgum (upland)	Wd&Bk	0.00558	0.93016	0.00404	0.99741	0.93016	0.99	0.0507	18
	Wood	0.00364	0.94820	0.00259	1.01950	0.94820	0.99	0.0476	18
Red maple	Wd&Bk	0.00240	1.02973	0.00488	0.88130	1.02973	0.98	0.0482	30
	Wood	0.00171	1.05004	0.00423	0.86117	1.05004	0.99	0.0471	30
Yellow-poplar	Wd&Bk	0.00311	0.98332	0.00239	1.03846	0.98332	0.99	0.0391	62
	Wood	0.00267	0.97804	0.00204	1.03346	0.97804	0.99	0.0405	62
Hard Hardwoods	Wd&Bk	0.00351	0.98106	0.00221	1.07756	0.98106	0.98	0.0556	347
	Wood	0.00216	1.01097	0.00157	1.07753	1.01097	0.98	0.0606	347
White ash	Wd&Bk	0.00389	0.97227	0.00437	0.94831	0.97227	0.98	0.0578	52
	Wood	0.00240	1.00222	0.00306	0.95133	1.00222	0.98	0.0581	52
Sweet birch	Wd&Bk	0.00754	0.90703	0.00495	0.99501	0.90703	0.99	0.0378	21
	Wood	0.00547	0.92188	0.00412	0.98078	0.92188	0.99	0.0344	21
Black locust	Wd&Bk	0.01034	0.84979	0.00356	1.07222	0.84979	0.97	0.0606	18
	Wood	0.00665	0.86588	0.00280	1.04662	0.86588	0.97	0.0604	18
Hickory	Wd&Bk	0.00102	1.11877	0.00124	1.07735	1.11877	0.99	0.0579	54
	Wood	0.00056	1.16061	0.00083	1.07704	1.16061	0.99	0.0593	54
Black oak	Wd&Bk	0.00318	0.97999	0.00111	1.19925	0.97999	0.99	0.0455	27
	Wood	0.00179	1.02067	0.00085	1.17661	1.02067	0.99	0.0451	27
Chestnut oak	Wd&Bk	0.00266	1.00944	0.00185	1.08446	1.00944	0.99	0.0562	51
	Wood	0.00168	1.02897	0.00122	1.09546	1.02897	0.99	0.0542	51
North. red oak	Wd&Bk	0.00448	0.95561	0.00294	1.04314	0.95561	0.99	0.0384	71
	Wood	0.00336	0.96872	0.00238	1.04053	0.96872	0.99	0.0379	71
Scarlet oak	Wd&Bk	0.00494	0.95073	0.00324	1.03857	0.95073	0.99	0.0418	27
	Wood	0.00264	0.99805	0.00205	1.05112	0.99805	0.99	0.0368	27
White oak	Wd&Bk	0.00371	0.97305	0.00150	1.16096	0.97305	0.99	0.0366	28
	Wood	0.00284	0.97894	0.00112	1.17278	0.97894	0.99	0.0321	28
All Species	Wd&Bk	0.00375	0.97203	0.00234	1.07007	0.97203	0.98	0.0557	475
	Wood	0.00242	0.99723	0.00174	1.06639	0.99723	0.98	0.0599	475

[1]Trees < 11.0 inches d.b.h.

$Y = a'(D^2Th)^b$

[2]Trees $\geq$ 11.0 inches d.b.h.

$Y = a''(D^2)^b(Th)^c$

Where: Y = component volume in cubic feet
D = tree d.b.h. in inches
Th = tree total height in feet
a', a", b, c = regression coefficients

[3]$\log_{10}$ form

Table 14.--Regression equations for estimating cubic-foot volume of the total-stem wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. and total height as the independent variables

Species or species group	Volume wood & bark or wood only	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL STEM					
Soft Hardwoods	Wd&Bk	0.00232	1.00250	0.00224	1.00966	1.00250	0.99	0.0403	128
	Wood	0.00166	1.02072	0.00193	0.98916	1.02072	0.99	0.0432	128
Basswood	Wd&Bk	0.00160	1.03943	0.00194	0.99928	1.03943	0.99	0.0395	18
	Wood	0.00094	1.07630	0.00109	1.04587	1.07630	0.99	0.0415	18
Blackgum (upland)	Wd&Bk	0.00201	1.01801	0.00250	0.97272	1.01801	0.99	0.0342	18
	Wood	0.00116	1.05448	0.00174	0.97115	1.05448	0.99	0.0283	18
Red maple	Wd&Bk	0.00313	0.96860	0.00427	0.90395	0.96860	0.99	0.0437	30
	Wood	0.00205	1.00321	0.00382	0.87340	1.00321	0.99	0.0446	30
Yellow-poplar	Wd&Bk	0.00235	1.00446	0.00237	1.00309	1.00446	0.99	0.0359	62
	Wood	0.00215	0.99360	0.00206	1.00256	0.99360	0.99	0.0369	62
Hard Hardwoods	Wd&Bk	0.00320	0.96878	0.00302	0.98064	0.96878	0.99	0.0465	347
	Wood	0.00196	1.00246	0.00209	0.98968	1.00246	0.99	0.0505	347
White ash	Wd&Bk	0.00432	0.93473	0.00386	0.95852	0.93473	0.98	0.0563	52
	Wood	0.00262	0.97061	0.00276	0.95927	0.97061	0.98	0.0574	52
Sweet birch	Wd&Bk	0.00446	0.93001	0.00394	0.95556	0.93001	0.99	0.0250	21
	Wood	0.00362	0.93932	0.00379	0.92974	0.93932	0.99	0.0276	21
Black locust	Wd&Bk	0.00935	0.83921	0.00248	1.11605	0.83921	0.96	0.0760	18
	Wood	0.00559	0.86772	0.00222	1.06058	0.86772	0.97	0.0697	18
Hickory	Wd&Bk	0.00144	1.05555	0.00193	0.99419	1.05555	0.99	0.0515	54
	Wood	0.00071	1.11439	0.00123	0.99890	1.11439	0.99	0.0548	54
Black oak	Wd&Bk	0.00311	0.96620	0.00242	1.01863	0.96620	0.99	0.0360	27
	Wood	0.00174	1.01004	0.00169	1.01653	1.01004	0.99	0.0362	27
Chestnut oak	Wd&Bk	0.00282	0.98847	0.00321	0.96142	0.98847	0.99	0.0501	51
	Wood	0.00173	1.01362	0.00186	0.99799	1.01362	0.99	0.0507	51
North. red oak	Wd&Bk	0.00463	0.92849	0.00370	0.97558	0.92849	0.99	0.0302	71
	Wood	0.00348	0.94423	0.00294	0.97909	0.94423	0.99	0.0308	71
Scarlet oak	Wd&Bk	0.00197	1.02777	0.00350	0.90801	1.02777	0.99	0.0241	27
	Wood	0.00119	1.06556	0.00233	0.92547	1.06556	0.99	0.0218	27
White oak	Wd&Bk	0.00307	0.97217	0.00296	0.97964	0.97217	0.99	0.0349	28
	Wood	0.00242	0.97936	0.00216	1.00348	0.97936	0.99	0.0335	28
All Species	Wd&Bk	0.00286	0.98063	0.00278	0.98659	0.98063	0.99	0.0453	475
	Wood	0.00186	1.00839	0.00204	0.98927	1.00839	0.99	0.0486	475

[1]Trees < 11.0 inches d.b.h.

$Y = a'(D^2Th)^b$

[2]Trees $\geq$ 11.0 inches d.b.h.

$Y = a''(D^2)^b(Th)^c$

Where: Y = component volume in cubic feet
D = tree d.b.h. in inches
Th = tree total height in feet
a', a", b, c = regression coefficients

[3]$\log_{10}$ form

Table 15.--Regression equations for estimating green and dry weight of the above-stump total-tree wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. and height to a 4-inch top as the independent variables

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL-TREE WOOD AND BARK					
Soft Hardwoods	Green	3.87800	0.66860	0.72890	1.01714	0.66860	0.98	0.0666	128
	Dry	1.95868	0.66739	0.31347	1.04946	0.66739	0.96	0.0907	128
Basswood	Green	2.04305	0.73478	0.58172	0.99672	0.73478	0.98	0.0540	18
	Dry	1.06650	0.71797	0.18270	1.08586	0.71797	0.98	0.0597	18
Blackgum (upland)	Green	4.23896	0.67201	1.37469	0.90682	0.67201	0.98	0.0638	18
	Dry	1.94174	0.68751	0.55848	0.94735	0.68751	0.98	0.0673	18
Red maple	Green	2.79645	0.72718	1.33332	0.88163	0.72718	0.98	0.0540	30
	Dry	1.48526	0.73274	0.61053	0.91811	0.73274	0.98	0.0593	30
Yellow-poplar	Green	3.11197	0.68358	0.49999	1.06483	0.68358	0.99	0.0506	62
	Dry	1.08338	0.71857	0.17801	1.09515	0.71857	0.99	0.0468	62
Hard Hardwoods	Green	2.39226	0.73786	0.37669	1.12332	0.73786	0.97	0.0779	347
	Dry	1.43617	0.74025	0.27244	1.08687	0.74025	0.98	0.0690	347
White ash	Green	2.50718	0.71370	0.57204	1.02182	0.71370	0.96	0.0809	52
	Dry	1.58972	0.71973	0.40270	1.00605	0.71973	0.96	0.0825	52
Sweet birch	Green	4.04501	0.69652	0.78224	1.03912	0.69652	0.99	0.0337	21
	Dry	2.40566	0.69623	0.47615	1.03399	0.69623	0.99	0.0347	21
Black locust	Green	1.94396	0.73625	0.52809	1.00799	0.73625	0.98	0.0557	18
	Dry	1.31417	0.73594	0.40396	0.98192	0.73594	0.97	0.0627	18
Hickory	Green	1.63821	0.78657	0.37653	1.09317	0.78657	0.98	0.0646	54
	Dry	1.06957	0.78530	0.27338	1.06975	0.78530	0.98	0.0635	54
Black oak	Green	1.53755	0.78627	0.29164	1.13291	0.78627	0.99	0.0415	27
	Dry	0.86880	0.78956	0.20407	1.09162	0.78956	0.99	0.0443	27
Chestnut oak	Green	1.36133	0.79879	0.33655	1.09018	0.79879	0.98	0.0608	51
	Dry	0.88762	0.79030	0.21614	1.08485	0.79030	0.98	0.0604	51
North. red oak	Green	2.01988	0.77154	0.61891	1.01818	0.77154	0.99	0.0438	71
	Dry	1.23446	0.76241	0.35828	1.02036	0.76241	0.99	0.0478	71
Scarlet oak	Green	4.10752	0.69123	0.70194	1.05962	0.69123	0.99	0.0431	27
	Dry	2.35170	0.69136	0.44376	1.03909	0.69136	0.99	0.0454	27
White oak	Green	3.58815	0.69390	0.27149	1.23218	0.69390	0.99	0.0502	28
	Dry	2.18335	0.69168	0.18557	1.20572	0.69168	0.99	0.0519	28
All Species	Green	2.95488	0.70930	0.42263	1.11480	0.70930	0.97	0.0818	475
	Dry	1.69369	0.71102	0.25268	1.10773	0.71102	0.95	0.0995	475

Continued

Table 15.--Regression equations for estimating green and dry weight of the above-stump total-tree wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. and height to a 4-inch top as the independent variables--Continued

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL-TREE WOOD					
Soft Hardwoods	Green	2.96375	0.67752	0.57084	1.02096	0.67752	0.97	0.0726	128
	Dry	1.45160	0.67951	0.24020	1.05463	0.67951	0.96	0.0957	128
Basswood	Green	1.39838	0.75067	0.34907	1.04005	0.75067	0.98	0.0533	18
	Dry	0.67563	0.73970	0.10124	1.13550	0.73970	0.98	0.0629	18
Blackgum (upland)	Green	3.23948	0.68264	1.17299	0.89447	0.68264	0.97	0.0727	18
	Dry	1.41496	0.69690	0.41741	0.95146	0.69690	0.96	0.0862	18
Red maple	Green	2.09711	0.74209	1.19238	0.85982	0.74209	0.98	0.0524	30
	Dry	1.04762	0.75450	0.54780	0.88970	0.75450	0.98	0.0580	30
Yellow-poplar	Green	2.27879	0.69674	0.38437	1.06786	0.69674	0.99	0.0504	62
	Dry	0.91051	0.71839	0.14811	1.09707	0.71839	0.99	0.0470	62
Hard Hardwoods	Green	1.70092	0.75597	0.30230	1.11618	0.75597	0.97	0.0794	347
	Dry	1.04156	0.75671	0.23324	1.06873	0.75671	0.97	0.0707	347
White ash	Green	1.61925	0.74327	0.45156	1.00955	0.74327	0.96	0.0800	52
	Dry	1.19503	0.73519	0.33202	1.00224	0.73519	0.96	0.0831	52
Sweet birch	Green	3.14751	0.70253	0.61852	1.04179	0.70253	0.99	0.0374	21
	Dry	1.96765	0.69578	0.40326	1.02628	0.69578	0.99	0.0390	21
Black locust	Green	1.60581	0.73849	0.37694	1.04069	0.73849	0.97	0.0639	18
	Dry	1.13645	0.73395	0.30391	1.00897	0.73395	0.97	0.0651	18
Hickory	Green	1.12061	0.80821	0.30283	1.08104	0.80821	0.98	0.0657	54
	Dry	0.77109	0.80320	0.23097	1.05457	0.80320	0.98	0.0674	54
Black oak	Green	0.99751	0.81466	0.24632	1.10630	0.81466	0.99	0.0451	27
	Dry	0.56446	0.81742	0.19472	1.03934	0.81742	0.99	0.0496	27
Chestnut oak	Green	1.01223	0.80684	0.25162	1.09709	0.80684	0.99	0.0582	51
	Dry	0.62573	0.80321	0.15840	1.08967	0.80321	0.99	0.0593	51
North. red oak	Green	1.53212	0.78474	0.50950	1.01431	0.78474	0.99	0.0441	71
	Dry	0.93166	0.77473	0.30265	1.00918	0.77473	0.99	0.0483	71
Scarlet oak	Green	2.65815	0.72045	0.51314	1.06342	0.72045	0.99	0.0420	27
	Dry	1.60282	0.71334	0.33673	1.03867	0.71334	0.99	0.0462	27
White oak	Green	3.02013	0.69348	0.22740	1.23277	0.69348	0.99	0.0483	28
	Dry	1.83047	0.69249	0.16065	1.14983	0.69249	0.99	0.0514	28
All Species	Green	2.15321	0.72432	0.33690	1.11110	0.72432	0.97	0.0845	475
	Dry	1.23450	0.72643	0.21000	1.09577	0.72643	0.95	0.1024	475

[1]Trees < 11.0 inches d.b.h.

$Y = a'(D^2H4)^b$

[2]Trees ≥ 11.0 inches d.b.h.

$Y = a''(D^2)^b (H4)^c$

Where: Y = component weight in pounds
D = tree d.b.h. in inches
H4 = tree height to 4-inch top in feet
a', a", b, c = regression coefficients

[3]$\log_{10}$ form

Table 16.--Regression equations for estimating green and dry weight of the total-stem wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. and height to a 4-inch top as the independent variables

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL-STEM WOOD AND BARK					
Soft Hardwoods	Green	2.70598	0.68917	0.58816	1.00742	0.68917	0.99	0.0485	128
	Dry	1.34721	0.69034	0.25043	1.04120	0.69034	0.98	0.0681	128
Basswood	Green	1.80352	0.72616	0.63852	0.94268	0.72616	0.99	0.0420	18
	Dry	0.94076	0.71033	0.19456	1.03894	0.71033	0.98	0.0496	18
Blackgum (upland)	Green	1.78861	0.74493	0.99337	0.86756	0.74493	0.99	0.0463	18
	Dry	0.83050	0.75941	0.40037	0.91156	0.75941	0.99	0.0526	18
Red maple	Green	3.08548	0.68327	1.13653	0.89152	0.68327	0.99	0.0406	30
	Dry	1.56821	0.69512	0.53992	0.91745	0.69512	0.99	0.0425	30
Yellow-poplar	Green	2.54447	0.69544	0.52654	1.02392	0.69544	0.99	0.0435	62
	Dry	0.89497	0.73079	0.18796	1.05619	0.73079	0.99	0.0418	62
Hard Hardwoods	Green	2.04725	0.73315	0.51514	1.02087	0.73315	0.98	0.0649	347
	Dry	1.23429	0.73505	0.39578	0.97221	0.73505	0.98	0.0552	347
White ash	Green	2.28808	0.69737	0.52864	1.00288	0.69737	0.98	0.0620	52
	Dry	1.47697	0.70182	0.37101	0.98989	0.70182	0.97	0.0651	52
Sweet birch	Green	3.03771	0.69307	0.63758	1.01860	0.69307	0.99	0.0367	21
	Dry	1.76762	0.69548	0.40309	1.00372	0.69548	0.99	0.0360	21
Black locust	Green	1.67174	0.73255	0.38808	1.03707	0.73255	0.97	0.0608	18
	Dry	1.16427	0.72894	0.31758	0.99982	0.72894	0.97	0.0663	18
Hickory	Green	1.88020	0.74741	0.55575	1.00155	0.74741	0.99	0.0513	54
	Dry	1.22829	0.74655	0.42129	0.96967	0.74655	0.99	0.0502	54
Black oak	Green	1.37979	0.78271	0.63488	0.94457	0.78271	0.99	0.0024	27
	Dry	0.78855	0.78452	0.50189	0.87873	0.78452	0.99	0.0281	27
Chestnut oak	Green	1.35011	0.78522	0.54270	0.97525	0.78522	0.99	0.0521	51
	Dry	0.88479	0.77634	0.36639	0.96018	0.77634	0.99	0.0508	51
North. red oak	Green	1.90954	0.75492	0.77247	0.94363	0.75492	0.99	0.0334	71
	Dry	1.19086	0.74208	0.46145	0.93977	0.74208	0.99	0.0359	71
Scarlet oak	Green	2.12715	0.74227	0.87900	0.92654	0.74227	1.00	0.0294	27
	Dry	1.22755	0.74017	0.60029	0.88933	0.74017	1.00	0.0315	27
White oak	Green	2.97960	0.69355	0.53612	1.05120	0.69355	0.99	0.0473	28
	Dry	1.84123	0.68976	0.39718	1.00958	0.68976	0.99	0.0504	28
All Species	Green	2.29643	0.71631	0.51504	1.02802	0.71631	0.98	0.0639	475
	Dry	1.30544	0.71901	0.32256	1.01051	0.71901	0.97	0.0784	475

Continued

Table 16.--Regression equations for estimating green and dry weight of the total-stem wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. and height to a 4-inch top as the independent variables--Continued

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL-STEM WOOD					
Soft Hardwoods	Green	2.14792	0.69749	0.49031	1.00551	0.69749	0.99	0.0548	128
	Dry	1.00818	0.70434	0.20072	1.04089	0.70434	0.97	0.0776	128
Basswood	Green	1.22165	0.74849	0.38011	0.99193	0.74849	0.99	0.0447	18
	Dry	0.58750	0.73878	0.10930	1.08944	0.73878	0.98	0.0552	18
Blackgum (upland)	Green	1.36219	0.76003	0.92697	0.84029	0.76003	0.98	0.0591	18
	Dry	0.59238	0.77606	0.33071	0.89760	0.77606	0.98	0.0763	18
Red maple	Green	2.22053	0.70795	1.05548	0.86304	0.70795	0.99	0.0393	30
	Dry	1.05063	0.72725	0.50125	0.88156	0.72725	0.99	0.0415	30
Yellow-poplar	Green	2.10187	0.69743	0.42224	1.03211	0.69743	0.99	0.0444	62
	Dry	0.76818	0.72896	0.15386	1.06425	0.72896	0.99	0.0420	62
Hard Hardwoods	Green	1.48446	0.75239	0.40565	1.02290	0.75239	0.98	0.0677	347
	Dry	0.90326	0.75324	0.32831	0.96427	0.75324	0.98	0.0579	347
White ash	Green	1.52026	0.72808	0.43468	0.98915	0.72808	0.97	0.0644	52
	Dry	1.12946	0.71879	0.31524	0.98489	0.71879	0.97	0.0666	52
Sweet birch	Green	2.56733	0.69624	0.58049	1.00625	0.69624	0.99	0.0414	21
	Dry	1.51926	0.69522	0.37731	0.98567	0.69522	0.99	0.0412	21
Black locust	Green	1.34884	0.74071	0.30875	1.04816	0.74071	0.97	0.0658	18
	Dry	0.97729	0.73344	0.26517	1.00544	0.73344	0.97	0.0668	18
Hickory	Green	1.24698	0.77656	0.42581	1.00061	0.77656	0.99	0.0556	54
	Dry	0.85661	0.77131	0.33818	0.96511	0.77131	0.99	0.0559	54
Black oak	Green	0.90801	0.81183	0.48979	0.94055	0.81183	0.99	0.0314	27
	Dry	0.51024	0.81433	0.42621	0.85185	0.81433	0.99	0.0360	27
Chestnut oak	Green	0.99043	0.79698	0.37229	1.00101	0.79698	0.99	0.5276	51
	Dry	0.61484	0.79264	0.24243	0.98669	0.79264	0.99	0.0528	51
North. red oak	Green	1.45796	0.76993	0.62520	0.94648	0.76993	0.99	0.0345	71
	Dry	0.90260	0.75622	0.37912	0.93710	0.75622	0.99	0.0372	71
Scarlet oak	Green	1.49501	0.76534	0.65249	0.93822	0.76534	1.00	0.0317	27
	Dry	0.86961	0.76041	0.45232	0.89671	0.76041	0.99	0.0348	27
White oak	Green	2.58959	0.69342	0.43846	1.06374	0.69342	0.99	0.0479	28
	Dry	1.58227	0.69095	0.33384	1.01539	0.69095	0.99	0.0524	28
All Species	Green	1.72268	0.73146	0.41085	1.03035	0.73146	0.98	0.0678	475
	Dry	0.96364	0.73579	0.26426	1.00556	0.73579	0.96	0.0838	475

[1]Trees < 11.0 inches d.b.h.

$$Y = a'(D^2H4)^b$$

[2]Trees ≥ 11.0 inches d.b.h.

$$Y = a''(D^2)^b (H4)^c$$

Where: Y = component weight in pounds
D = tree d.b.h. in inches
H4 = tree height to 4-inch top in feet
a', a", b, c = regression coefficients

[3]$\log_{10}$ form

Table 17.--Regression equations for estimating cubic-foot volume of the above-stump total-tree wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. and height to a 4-inch top as the independent variables

Species or species group	Volume wood & bark or wood only	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL TREE					
Soft Hardwoods	Wd&Bk	0.05474	0.70054	0.01130	1.02957	0.70054	0.99	0.0485	128
	Wood	0.04134	0.70969	0.00937	1.01925	0.70969	0.99	0.0535	128
Basswood	Wd&Bk	0.04080	0.73184	0.00749	1.08520	0.73184	0.98	0.0565	18
	Wood	0.02709	0.75153	0.00439	1.13087	0.75153	0.98	0.0545	18
Blackgum (upland)	Wd&Bk	0.05331	0.70720	0.01657	0.95079	0.70720	0.99	0.0497	18
	Wood	0.03752	0.71700	0.01067	0.97912	0.71700	0.99	0.0524	18
Red maple	Wd&Bk	0.04535	0.73493	0.01864	0.92030	0.73493	0.98	0.0538	30
	Wood	0.03424	0.74945	0.01656	0.90088	0.74945	0.98	0.0530	30
Yellow-poplar	Wd&Bk	0.05378	0.69692	0.00918	1.06554	0.69692	0.99	0.0367	62
	Wood	0.04522	0.69357	0.00780	1.05996	0.69357	0.99	0.0376	62
Hard Hardwoods	Wd&Bk	0.03974	0.73923	0.00750	1.08690	0.73923	0.98	0.0595	347
	Wood	0.02666	0.76032	0.00552	1.08874	0.76032	0.98	0.0656	347
White ash	Wd&Bk	0.04333	0.72793	0.01052	1.02317	0.72793	0.97	0.0704	52
	Wood	0.02863	0.75098	0.00760	1.02761	0.75098	0.97	0.0709	52
Sweet birch	Wd&Bk	0.06728	0.69628	0.01934	0.95624	0.69628	0.99	0.0333	21
	Wood	0.05171	0.70489	0.01635	0.94500	0.70489	0.99	0.0335	21
Black locust	Wd&Bk	0.03373	0.75125	0.01325	0.94608	0.75125	0.98	0.0525	18
	Wood	0.02223	0.76526	0.01066	0.91850	0.76526	0.99	0.0522	18
Hickory	Wd&Bk	0.02357	0.79863	0.00527	1.11100	0.79863	0.98	0.0637	54
	Wood	0.01416	0.83119	0.00374	1.10881	0.83119	0.99	0.0625	54
Black oak	Wd&Bk	0.02878	0.76935	0.00172	1.35720	0.76935	0.99	0.0403	27
	Wood	0.01803	0.79928	0.00402	1.11227	0.79928	0.99	0.0416	27
Chestnut oak	Wd&Bk	0.02749	0.77663	0.00642	1.07994	0.77663	0.98	0.0578	51
	Wood	0.01788	0.79366	0.00434	1.08868	0.79366	0.99	0.0834	51
North. red oak	Wd&Bk	0.03597	0.75490	0.00986	1.02482	0.75490	0.99	0.0415	71
	Wood	0.02777	0.76524	0.00811	1.02199	0.76524	0.99	0.0411	71
Scarlet oak	Wd&Bk	0.07180	0.67727	0.01056	1.07687	0.67727	0.99	0.0444	27
	Wood	0.04451	0.70926	0.00706	1.09332	0.70926	0.99	0.0424	27
White oak	Wd&Bk	0.05516	0.69940	0.00486	1.20595	0.69940	0.99	0.0453	28
	Wood	0.04323	0.70290	0.00364	1.21889	0.70290	0.99	0.0430	28
All Species	Wd&Bk	0.04521	0.72360	0.00823	1.07891	0.72360	0.98	0.0578	475
	Wood	0.03169	0.74013	0.00627	1.07802	0.74013	0.98	0.0639	475

[1]Trees < 11.0 inches d.b.h.

$$Y = a'(D^2H4)^b$$

[2]Trees ≥ 11.0 inches d.b.h.

$$Y = a''(D^2)^b (H4)^c$$

Where: Y = component volume in cubic feet
D = tree d.b.h. in inches
H4 = tree height to 4-inch top in feet
a', a", b, c = regression coefficients

[3]$\log_{10}$ form

Table 18.--Regression equations for estimating cubic-foot volume of the total-stem wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. and height to a 4-inch top as the independent variables

Species or species group	Volume wood & bark or wood only	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL STEM					
Soft Hardwoods	Wd&Bk	0.03746	0.72416	0.00871	1.02837	0.72416	0.99	0.0414	128
	Wood	0.02856	0.73561	0.00764	1.01048	0.73561	0.99	0.0470	128
Basswood	Wd&Bk	0.03371	0.73050	0.00778	1.03617	0.73050	0.99	0.0039	18
	Wood	0.02195	0.75703	0.00460	1.08296	0.75703	0.99	0.0395	18
Blackgum (upland)	Wd&Bk	0.02359	0.77495	0.01177	0.91997	0.77495	0.99	0.0300	18
	Wood	0.01543	0.79862	0.00846	0.92396	0.79862	0.99	0.0345	18
Red maple	Wd&Bk	0.04727	0.69759	0.01562	0.92844	0.69759	0.99	0.0390	30
	Wood	0.03392	0.72326	0.01472	0.89732	0.72326	0.99	0.0383	30
Yellow-poplar	Wd&Bk	0.04350	0.71115	0.00936	1.03155	0.71115	0.99	0.0346	62
	Wood	0.03834	0.70393	0.00802	1.03020	0.70393	0.99	0.0348	62
Hard Hardwoods	Wd&Bk	0.03369	0.73486	0.01017	0.98455	0.73486	0.99	0.0458	347
	Wood	0.02288	0.75831	0.00732	0.99601	0.75831	0.99	0.0520	347
White ash	Wd&Bk	0.04012	0.71050	0.00929	1.01546	0.71050	0.98	0.0593	52
	Wood	0.02669	0.73667	0.00686	1.01996	0.73667	0.98	0.0616	52
Sweet birch	Wd&Bk	0.04491	0.70572	0.01558	0.92643	0.70572	0.99	0.0331	21
	Wood	0.03732	0.71290	0.01520	0.90017	0.71290	0.99	0.0351	21
Black locust	Wd&Bk	0.02878	0.74727	0.00937	0.98133	0.74727	0.97	0.0658	18
	Wood	0.01809	0.77187	0.00872	0.92407	0.77187	0.98	0.0589	18
Hickory	Wd&Bk	0.02651	0.75977	0.00766	1.01864	0.75977	0.99	0.0499	54
	Wood	0.01507	0.80356	0.00526	1.02305	0.80356	0.99	0.0513	54
Black oak	Wd&Bk	0.02665	0.76146	0.01062	0.95328	0.76146	0.99	0.0243	27
	Wood	0.01672	0.79414	0.00794	0.94946	0.79414	0.99	0.0268	27
Chestnut oak	Wd&Bk	0.02773	0.76059	0.01082	0.95689	0.76059	0.99	0.0518	51
	Wood	0.01767	0.78232	0.00650	0.99076	0.78232	0.99	0.0492	51
North. red oak	Wd&Bk	0.03440	0.73586	0.01199	0.95561	0.73586	0.99	0.0311	71
	Wood	0.02670	0.74844	0.00974	0.95868	0.74844	0.99	0.0316	71
Scarlet oak	Wd&Bk	0.03592	0.73107	0.01253	0.95066	0.73107	0.99	0.0311	27
	Wood	0.02446	0.75654	0.00873	0.97133	0.75654	0.99	0.0327	27
White oak	Wd&Bk	0.04510	0.70008	0.00958	1.02305	0.70008	0.99	0.0418	28
	Wood	0.03659	0.70428	0.00703	1.04835	0.70428	0.99	0.0423	28
All Species	Wd&Bk	0.03463	0.73223	0.00992	0.99296	0.73223	0.99	0.0451	475
	Wood	0.02463	0.75060	0.00750	0.99852	0.75060	0.99	0.0512	475

[1]Trees < 11.0 inches d.b.h.

$Y = a'(D^2H4)^b$

[2]Trees $\geq$ 11.0 inches d.b.h.

$Y = a''(D^2)^b (H4)^c$

Where: Y = component volume in cubic feet
D = tree d.b.h. in inches
H4 = tree height to 4-inch top in feet
a', a", b, c = regression coefficients

[3]$\log_{10}$ form

Table 19.--Regression equations for estimating green and dry weight of the above-stump total-tree wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. and saw-log merchantable height as the independent variables

Species or species group	Weight green or dry	Regression equation coefficients[1] a	b	c	Coefficient of determination (R^2)	Standard error[2] ($S_{y.x}$)	No. of trees sampled
			TOTAL-TREE WOOD AND BARK				
Soft Hardwoods	Green	4.05976	1.15137	0.11698	0.95	0.0556	64
	Dry	1.86603	1.19791	0.07544	0.94	0.0648	64
Yellow-poplar	Green	3.63549	1.15471	0.14090	0.96	0.0514	38
	Dry	1.31796	1.18011	0.18123	0.97	0.0518	38
Hard Hardwoods	Green	2.98611	1.20675	0.16314	0.90	0.0728	194
	Dry	2.50064	1.17013	0.12749	0.90	0.0708	194
White ash	Green	4.12121	1.24290	-0.04067	0.87	0.0738	22
	Dry	3.48126	1.21437	-0.06425	0.86	0.0762	22
Hickory	Green	4.43712	1.18669	0.11729	0.94	0.0540	33
	Dry	3.05128	1.15651	0.13495	0.93	0.0582	33
Black oak	Green	3.41609	1.23276	0.06840	0.97	0.0381	18
	Dry	2.73215	1.17562	0.06050	0.97	0.0386	18
Chestnut oak	Green	3.58371	1.05408	0.32267	0.93	0.0571	32
	Dry	2.48376	1.05737	0.28062	0.93	0.0575	32
North. red oak	Green	5.99037	1.10049	0.15495	0.96	0.0470	35
	Dry	3.46886	1.09854	0.15107	0.95	0.0525	35
Scarlet oak	Green	4.53057	1.21071	0.04946	0.96	0.0489	18
	Dry	2.91232	1.19164	0.04318	0.95	0.0538	18
White oak	Green	2.35939	1.28245	0.14044	0.97	0.0430	19
	Dry	1.32111	1.26763	0.17245	0.97	0.0458	19
All Species	Green	3.35825	1.22626	0.09181	0.90	0.0754	258
	Dry	2.35086	1.24448	0.01370	0.86	0.0924	258

Continued

Table 19.--Regression equations for estimating green and dry weight of the above-stump total-tree wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. and saw-log merchantable height as the independent variables--Continued

Species or species group	Weight green or dry	Regression equation coefficients[1] a	b	c	Coefficient of determination (R^2)	Standard error[2] ($S_{y.x}$)	No. of trees sampled
			TOTAL-TREE WOOD				
Soft Hardwoods	Green	3.24470	1.16033	0.11400	0.94	0.0593	64
	Dry	1.37310	1.20500	0.09655	0.92	0.0731	64
Yellow-poplar	Green	2.79150	1.16660	0.14325	0.96	0.0553	38
	Dry	0.99658	1.19403	0.18713	0.96	0.0558	38
Hard Hardwoods	Green	2.32731	1.20508	0.18321	0.90	0.0750	194
	Dry	2.12789	1.15769	0.13923	0.89	0.0751	194
White ash	Green	3.45613	1.24018	-0.03654	0.87	0.0732	22
	Dry	2.91578	1.22271	-0.06896	0.85	0.7690	22
Hickory	Green	3.26847	1.15941	0.18233	0.94	0.0572	33
	Dry	2.44480	1.13369	0.18065	0.92	0.0637	33
Black oak	Green	3.11513	1.20511	0.08186	0.97	0.0419	18
	Dry	3.37766	1.10757	0.04619	0.96	0.0435	18
Chestnut oak	Green	2.49920	1.05608	0.35718	0.93	0.0564	32
	Dry	1.72630	1.05331	0.32219	0.93	0.0590	32
North. red oak	Green	4.98757	1.09466	0.16954	0.96	0.0473	35
	Dry	2.97391	1.08462	0.16492	0.95	0.0519	35
Scarlet oak	Green	3.73344	1.21738	0.04638	0.96	0.0514	18
	Dry	2.60260	1.19230	0.02328	0.94	0.0580	18
White oak	Green	1.66906	1.29182	0.17117	0.97	0.0468	19
	Dry	0.93583	1.27017	0.21334	0.96	0.0507	19
All Species	Green	2.65966	1.22734	0.10322	0.90	0.0780	258
	Dry	1.90465	1.23786	0.02986	0.84	0.0969	258

[1] $Y = a(D^2)^b (Mh)^c$

Where: Y = component weight in pounds
D = tree d.b.h. in inches
Mh = tree saw-log merchantable height in feet
a,b,c = regression coefficients

[2] $\log_{10}$ form

Table 20.--Regression equations for estimating green and dry weight of the saw-log merchantable stem wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. and saw-log merchantable height as the independent variables

Species or species group	Weight green or dry	Regression equation coefficients[1] a	b	c	Coefficient of determination (R^2)	Standard error[2] ($S_{y.x}$)	No. of trees sampled
			SAW-LOG STEM WOOD AND BARK				
Soft Hardwoods	Green	0.55968	0.97608	0.76439	0.98	0.0394	64
	Dry	0.24291	1.03375	0.72406	0.97	0.0531	64
Yellow-poplar	Green	0.68901	1.06155	0.59776	0.98	0.0388	38
	Dry	0.23686	1.10009	0.63576	0.98	0.0399	38
Hard Hardwoods	Green	0.42639	1.04226	0.78699	0.96	0.0529	194
	Dry	0.38048	0.99659	0.74397	0.96	0.0468	194
White ash	Green	0.37684	1.09124	0.68547	0.97	0.0449	22
	Dry	0.31732	1.06878	0.65457	0.96	0.0494	22
Hickory	Green	0.58322	1.00433	0.76511	0.99	0.0303	33
	Dry	0.42405	0.96934	0.77888	0.98	0.0328	33
Black oak	Green	0.49216	1.04357	0.74573	0.99	0.0145	18
	Dry	0.46869	0.95839	0.72629	0.98	0.0228	18
Chestnut oak	Green	0.63082	0.95792	0.80829	0.98	0.0342	32
	Dry	0.45925	0.95093	0.94403	0.98	0.0344	32
North. red oak	Green	0.76656	0.99153	0.72285	0.98	0.0324	35
	Dry	0.43066	0.99038	0.71939	0.98	0.0374	35
Scarlet oak	Green	0.69724	0.96281	0.78401	0.99	0.0250	18
	Dry	0.45295	0.92838	0.78994	0.98	0.0286	18
White oak	Green	0.49208	1.08126	0.70438	0.93	0.0601	19
	Dry	0.27107	1.05723	0.74927	0.94	0.0562	19
All Species	Green	0.47048	1.06146	0.72104	0.95	0.0593	258
	Dry	0.33634	1.07137	0.64708	0.92	0.0762	258

Continued

Table 20.--Regression equations for estimating green and dry weight of the saw-log merchantable stem wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. and saw-log merchantable height as the independent variables--Continued

Species or species group	Weight green or dry	Regression equation coefficients[1] a	b	c	Coefficient of determination (R^2)	Standard error[2] ($S_{Y \cdot X}$)	No. of trees sampled
			SAW-LOG STEM WOOD				
Soft Hardwoods	Green	0.50293	0.99146	0.73096	0.98	0.0450	64
	Dry	0.20254	1.04938	0.70802	0.96	0.0621	64
Yellow-poplar	Green	0.55389	1.08099	0.58465	0.98	0.0430	38
	Dry	0.18726	1.12510	0.61962	0.98	0.0453	38
Hard Hardwoods	Green	0.35194	1.04701	0.79339	0.96	0.0538	194
	Dry	0.33381	0.99188	0.74595	0.96	0.0493	194
White ash	Green	0.34623	1.08809	0.67732	0.96	0.0470	22
	Dry	0.28903	1.07233	0.64416	0.95	0.0511	22
Hickory	Green	0.46205	0.99169	0.80794	0.99	0.0312	33
	Dry	0.34990	0.95888	0.80950	0.98	0.0366	33
Black oak	Green	0.47034	1.02642	0.74214	0.99	0.0207	18
	Dry	0.57210	0.90650	0.70112	0.97	0.0273	18
Chestnut oak	Green	0.43231	0.97235	0.84074	0.98	0.0367	32
	Dry	0.30374	0.96258	0.80876	0.97	0.0391	32
North. red oak	Green	0.66689	0.99419	0.72204	0.98	0.0332	35
	Dry	0.37474	0.98637	0.72305	0.98	0.0377	35
Scarlet oak	Green	0.60720	0.97327	0.77023	0.99	0.0261	18
	Dry	0.41128	0.93365	0.76718	0.98	0.0304	18
White oak	Green	0.37821	1.08957	0.72864	0.93	0.0618	19
	Dry	0.20442	1.05844	0.78758	0.93	0.0587	19
All Species	Green	0.40454	1.06936	0.71126	0.95	0.0619	258
	Dry	0.29232	1.07303	0.64172	0.91	0.0803	258

[1] $Y = a(D^2)^b(Mh)^c$

Where: Y = component weight in pounds
D = tree d.b.h. in inches
Mh = tree saw-log merchantable height in feet
a,b,c = regression coefficients

[2] $\log_{10}$ form

Table 21.--Regression equations for estimating cubic-foot volume of the above-stump total-tree wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. and saw-log merchantable height as the independent variables

Species or species group	Volume wood & bark or wood only	Regression equation coefficients[1] a	b	c	Coefficient of determination (R^2)	Standard error[2] ($S_{y.x}$)	No. of trees sampled
			TOTAL TREE				
Soft Hardwoods	Wd&Bk	0.06348	1.15377	0.16627	0.96	0.0542	64
	Wood	0.05071	1.17519	0.14022	0.95	0.0593	64
Yellow-poplar	Wd&Bk	0.05911	1.09737	0.26467	0.98	0.0424	38
	Wood	0.04603	1.11422	0.25069	0.97	0.0466	38
Hard Hardwoods	Wd&Bk	0.06694	1.17704	0.12273	0.93	0.0574	194
	Wood	0.04642	1.19770	0.13386	0.92	0.0637	194
White ash	Wd&Bk	0.06137	1.22971	0.05813	0.91	0.0628	22
	Wood	0.04236	1.26906	0.04386	0.91	0.0630	22
Hickory	Wd&Bk	0.07906	1.21638	0.04475	0.95	0.0526	33
	Wood	0.05522	1.19934	0.10844	0.94	0.0539	33
Black oak	Wd&Bk	0.04500	1.24048	0.11235	0.98	0.0345	18
	Wood	0.04156	1.21387	0.11566	0.97	0.0379	18
Chestnut oak	Wd&Bk	0.07369	1.05046	0.26836	0.95	0.0496	32
	Wood	0.04431	1.05971	0.31747	0.95	0.0493	32
North. red oak	Wd&Bk	0.09386	1.09528	0.15845	0.96	0.0465	35
	Wood	0.07549	1.09058	0.17826	0.96	0.0469	35
Scarlet oak	Wd&Bk	0.06083	1.23182	0.05781	0.96	0.0475	18
	Wood	0.04770	1.24873	0.05083	0.96	0.0491	18
White oak	Wd&Bk	0.04580	1.26747	0.10850	0.97	0.0390	19
	Wood	0.03026	1.29052	0.13024	0.97	0.0414	19
All Species	Wd&Bk	0.06486	1.17578	0.13215	0.94	0.0565	258
	Wood	0.04764	1.19441	0.13107	0.93	0.0623	258

[1] $Y = a(D^2)^b(Mh)^c$

Where: Y = component volume in cubic feet
D = tree d.b.h. in inches
Mh = saw-log merchantable height in feet
a,b,c = regression coefficients

[2] $\log_{10}$ form

Table 22.--Regression equations for estimating cubic-foot volume of the saw-log merchantable-stem wood and bark combined and wood alone for hardwood species in the Southern Appalachian Mountains, with d.b.h. and saw-log merchantable height as the independent variables

Species or species group	Volume wood & bark or wood only	Regression equation coefficients[1] a	b	c	Coefficient of determination (R^2)	Standard error[2] ($S_{y.x}$)	No. of trees sampled
			SAW-LOG STEM				
Soft Hardwoods	Wd&Bk	0.00780	0.99177	0.82682	0.99	0.0330	64
	Wood	0.00701	1.02126	0.76649	0.99	0.0348	64
Yellow-poplar	Wd&Bk	0.01052	1.01910	0.72073	0.99	0.0283	38
	Wood	0.00841	1.04599	0.69141	0.99	0.0320	38
Hard Hardwoods	Wd&Bk	0.00967	1.01633	0.73612	0.98	0.0378	194
	Wood	0.00722	1.04258	0.73139	0.97	0.0408	194
White ash	Wd&Bk	0.00507	1.10571	0.77375	0.97	0.0407	22
	Wood	0.00393	1.13881	0.74777	0.97	0.0425	22
Hickory	Wd&Bk	0.01177	1.03084	0.66606	0.98	0.0348	33
	Wood	0.00910	1.02807	0.69683	0.98	0.0337	33
Black oak	Wd&Bk	0.00640	1.05525	0.78692	0.99	0.0189	18
	Wood	0.00616	1.03754	0.77832	0.99	0.0214	18
Chestnut oak	Wd&Bk	0.01297	0.95130	0.75417	0.97	0.0389	32
	Wood	0.00758	0.97846	0.79829	0.97	0.0375	32
North. red oak	Wd&Bk	0.01156	0.99620	0.71988	0.98	0.0331	35
	Wood	0.00983	1.00126	0.72005	0.98	0.0337	35
Scarlet oak	Wd&Bk	0.00922	0.98666	0.79196	0.99	0.0247	18
	Wood	0.00770	1.00493	0.77708	0.99	0.0265	18
White oak	Wd&Bk	0.00959	1.07178	0.66050	0.93	0.0578	19
	Wood	0.00723	1.09265	0.66626	0.93	0.0578	19
All Species	Wd&Bk	0.00876	1.01407	0.76589	0.98	0.0370	258
	Wood	0.00707	1.04112	0.73845	0.98	0.0394	258

[1] $Y = a(D^2)^b(Mh)^c$

Where: Y = component volume in cubic feet
D = tree d.b.h. in inches
Mh = saw-log merchantable height in feet
a,b,c = regression coefficients

[2] $\log_{10}$ form

Table 23.--Regression coefficients for estimating above-stump stem weight to a specified d.o.b. top diameter as a proportion of the total-stem weight for hardwood species in the Southern Appalachian Mountains

Species	Regression equation and coefficients[1] $Y_R = e^{a(d)^b (D)^c}$					
	Green weight			Dry weight		
	a	b	c	a	b	c
WOOD AND BARK						
Soft Hardwoods	-2.21340	3.69663	-4.00734	-2.32156	3.64529	-3.97653
Basswood	-1.29361	3.91860	-4.02401	-1.28273	3.87891	-3.97929
Blackgum (upland)	-1.67063	4.31740	-4.55837	-1.62090	4.27337	-4.51105
Red maple	-1.48733	4.07172	-4.15788	-1.43083	4.05497	-4.12303
Yellow-poplar	-3.13237	3.24562	-3.77925	-3.54839	3.17747	-3.76535
Hard Hardwoods	-2.16093	3.80095	-4.16788	-2.16635	3.76999	-4.13510
White ash	-0.85286	3.25306	-3.30904	-0.84279	3.28603	-3.33279
Sweet birch	-0.86248	4.24300	-4.12996	-0.81251	4.21844	-4.08482
Black locust	-1.43964	3.34777	-3.55779	-1.27900	3.33578	-3.49181
Hickory	-4.46031	3.84056	-4.44415	-4.48018	3.83474	-4.43554
Black oak	-4.21018	3.91449	-4.53626	-4.35164	3.85984	-4.49173
Chestnut oak	-2.33213	4.00430	-4.37862	-2.25664	4.00092	-4.35574
North. red oak	-1.78853	4.05625	-4.35269	-1.90345	3.95236	-4.27185
Scarlet oak	-2.56711	3.67652	-4.17429	-2.65117	3.58558	-4.09877
White oak	-12.89794	2.66329	-4.01784	-12.00001	2.64614	-3.96330
All Species	-2.18145	3.83824	-4.18924	-2.19443	3.79947	-4.15151
WOOD ONLY						
Soft Hardwoods	-2.14922	3.76998	-4.07255	-2.24102	3.72688	-4.04629
Basswood	-1.09439	4.07301	-4.11466	-1.05926	4.01311	-4.04160
Blackgum (upland)	-1.45781	4.43140	-4.61952	-1.34282	4.39292	-4.56007
Red maple	-1.37214	4.19926	-4.25422	-1.33864	4.16262	-4.20601
Yellow-poplar	-3.16748	3.28202	-3.82586	-3.51229	3.24724	-3.83278
Hard Hardwoods	-2.00963	3.93252	-4.27051	-2.05785	3.87551	-4.22144
White ash	-0.79212	3.40027	-3.42870	-0.80589	3.38150	-3.41391
Sweet birch	-0.76917	4.34999	-4.19013	-0.72051	4.31785	-4.13646
Black locust	-1.42866	3.44696	-3.65524	-1.27952	3.42285	-3.58019
Hickory	-4.23466	3.96634	-4.54756	-4.36489	3.93623	-4.52542
Black oak	-3.74181	4.01847	-4.59825	-3.94567	3.93141	-4.53034
Chestnut oak	-2.23141	4.17046	-4.53052	-2.22131	4.14820	-4.50149
North. red oak	-1.64068	4.17440	-4.43072	-1.76424	4.05667	-4.34109
Scarlet oak	-2.34160	3.76911	-4.22934	-2.49944	3.64618	-4.13742
White oak	-13.82341	2.74531	-4.14893	-12.83857	2.72014	-4.08425
All Species	-2.03288	3.95927	-4.28299	-2.06850	3.90215	-4.23251

[1]Where: Y_R = stem weight to top d.o.b./total-stem weight ratio
d = stem specified top d.o.b. in inches
D = tree diameter at breast height in inches
a,b,c = regression coefficients
e = 2.71828 (base of log E)

Table 24.--Regression coefficients for estimating above-stump stem volume to a specified d.o.b. top diameter as a proportion of the total-stem volume for hardwood species in the Southern Appalachian Mountains

Species	Regression equation and coefficients[1] $Y_R = e^{a(d)^b (D)^c}$					
	Wood and bark			Wood only		
	a	b	c	a	b	c
Soft Hardwoods	-2.65041	3.63613	-4.02198	-2.49527	3.75217	-4.11106
Basswood	-1.57495	3.83251	-4.01512	-1.44150	3.94456	-4.09578
Blackgum (upland)	-3.11888	4.50575	-4.98933	-3.00702	4.60007	-5.08323
Red maple	-1.64317	3.97988	-4.10493	-1.56405	4.07950	-4.18514
Yellow-poplar	-4.18242	3.20385	-3.86194	-3.93057	3.33593	-3.96294
Hard Hardwoods	-2.11609	3.69565	-4.06590	-2.01927	3.85912	-4.20784
White ash	-0.83488	3.28203	-3.33403	-0.81118	3.41128	-3.45707
Sweet birch	-0.54868	4.13144	-3.86409	-0.47153	4.25228	-3.92355
Black locust	-1.33357	3.33736	-3.51539	-1.72742	3.92136	-4.14425
Hickory	-4.10624	3.76795	-4.35556	-3.74791	3.90765	-4.45962
Black oak	-4.24857	3.92307	-4.55072	-3.86927	4.03853	-4.63239
Chestnut oak	-1.89796	3.77009	-4.07300	-1.81088	3.92867	-4.21943
North. red oak	-2.08619	3.93878	-4.30635	-1.97257	4.04188	-4.38210
Scarlet oak	-2.72820	3.63031	-4.15933	-2.77208	3.93948	-4.44871
White oak	-13.81307	2.63083	-4.00315	-14.82177	2.71406	-4.13623
All Species	-2.29927	3.76224	-4.14072	-2.18185	3.90966	-4.26572

[1]Where: Y_R = stem volume to top d.o.b./total-stem volume ratio

d = stem specified top d.o.b. in inches

D = tree diameter at breast height in inches

a,b,c = regression coefficients

e = 2.71828 (base of log E)

Table 25.--Regression coefficients for estimating stem weight to a specified d.o.b. top diameter as a proportion of the saw-log stem weight for hardwood species in the Southern Appalachian Mountains

Species	Ratio equation and coefficients[1] $Y_R = e^{a(Mh)^b((1-(\frac{d}{.78D})^2)^2)^c}$					
	Green weight			Dry weight		
	a	b	c	a	b	c
			WOOD AND BARK			
Soft Hardwoods	20.03667	-1.15011	0.30738	22.65502	-1.17892	0.30687
Yellow-poplar	10.22822	-0.98536	0.36914	13.88862	-1.05701	0.35508
Hard Hardwoods	21.83094	-1.20030	0.34703	22.05487	-1.19924	0.35256
White ash	7.59795	-0.84256	0.34097	9.74167	-0.91132	0.33776
Hickory	5.62084	-0.78282	0.33669	6.31538	-0.81008	0.34761
Black oak	8.59159	-0.96498	0.34859	10.22071	-1.00848	0.36275
Chestnut oak	10.16324	-1.02615	0.34438	11.77550	-1.06016	0.35889
North. red oak	11.43588	-1.07021	0.33698	12.89204	-1.09324	0.35282
Scarlet oak	13.89580	-1.14183	0.33685	16.33739	-1.18006	0.35211
White oak	9.77724	-1.03753	0.24075	11.57127	-1.07768	0.24979
All Species	22.10956	-1.19842	0.33093	23.34055	-1.20928	0.33401
			WOOD ONLY			
Soft Hardwoods	19.97709	-1.15553	0.30428	22.66578	-1.18538	0.30423
Yellow-poplar	9.93078	-0.98459	0.36906	13.76196	-1.06203	0.35548
Hard Hardwoods	22.56773	-1.21533	0.34214	21.93139	-1.20369	0.34429
White ash	7.64692	-0.85097	0.33715	9.74286	-0.91666	0.33500
Black oak	8.45354	-0.96445	0.34659	8.46965	-0.96165	0.34694
Hickory	5.58002	-0.78519	0.33356	5.64166	-0.78507	0.33487
Chestnut oak	10.71803	-1.05121	0.33926	10.71403	-1.04734	0.34011
North. red oak	11.20075	-1.06846	0.33485	10.98689	-1.05719	0.33593
Scarlet oak	13.44225	-1.13557	0.33509	13.58787	-1.13547	0.33509
White oak	9.93996	-1.04879	0.24099	9.78499	-1.03963	0.24026
All Species	22.54655	-1.20977	0.32670	23.23192	-1.21400	0.32802

Y_R = ratio of stem weight or volume to top d.o.b. to saw-log stem

Mh = saw-log merchantable height in feet

d = specified top diameter in inches

D = tree diameter at breast height in inches

.78 = constant based on average form class

a,b,c = regression coefficients

e = base of natural log

Table 26.--Regression coefficients for estimating stem volume to a specified d.o.b. top diameter as a proportion of the saw-log stem volume for hardwood species in the Southern Appalachian Mountains

Species	Ratio equation and coefficients[1] $Y_R = e^{a(Mh)^b}((1-(\frac{d}{.78D})^2)^2)^c$					
	Wood and bark			Wood only		
	a	b	c	a	b	c
Soft Hardwoods	17.02169	-1.10696	0.30429	16.72438	-1.10825	0.30068
Yellow-poplar	9.53972	-0.97107	0.36942	9.08017	-0.96511	0.36804
Hard Hardwoods	18.34030	-1.15240	0.34627	18.69832	-1.16454	0.34023
White ash	6.19949	-0.78674	0.33896	6.14057	-0.79208	0.33351
Hickory	4.46825	-0.72269	0.33443	4.25711	-0.71497	0.33028
Black oak	7.13860	-0.91520	0.34770	6.68841	-0.90165	0.34567
Chestnut oak	7.98372	-0.95562	0.34672	8.18125	-0.97506	0.34032
North. red oak	9.70538	-1.02782	0.33574	9.06390	-1.01358	0.33344
Scarlet oak	12.08963	-1.10806	0.33484	11.17720	-1.09039	0.33229
White oak	8.12968	-0.98631	0.23765	7.84004	-0.98376	0.23730
All Species	18.67262	-1.15229	0.32937	18.84524	-1.16148	0.32498

Y_R = ratio of stem weight or volume to top d.o.b. to saw-log stem

Mh = saw-log merchantable height in feet

d = specified top diameter in inches

D = tree diameter at breast height in inches

.78 = constant based on average form class

a,b,c = regression coefficients

e = base of natural log

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Clark, Alexander, III; Schroeder, James G.
Weight, volume, and physical properties of major hardwood species in the Southern Appalachian Mountains. Res. Pap. SE-253. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1985. 63 pp.

The weight, volume, and physical properties of trees 1 to 20 inches d.b.h. were determined for basswood, blackgum (upland), red maple, yellow-poplar, white oak, sweet birch, black locust, hickory, black oak, chestnut oak, northern red oak, scarlet oak, and white oak in the Southern Appalachian Mountains. Hard hardwoods, soft hardwoods, and individual species equations are presented for predicting green and dry weight and green volume of the total tree above-stump and its components by using d.b.h. and total height, d.b.h. and height to a 4-inch top, d.b.h. and saw-log merchantable height, and d.b.h. alone. Average specific gravity, moisture content, and weight per cubic foot of wood, bark, and wood and bark combined are presented for each species by tree size class and component. Bark percentage is also presented for each species by tree size class and component.

Keywords: Biomass, equations, specific gravity, moisture content, bark percentage, weight per cubic foot.

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Keywords: Biomass, equations, specific gravity, moisture content, bark percentage, weight per cubic foot.

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Lamination of Composite Framing With Melamine-Formaldehyde Adhesive and Radio-Frequency Curing

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May 1986

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Lamination of Composite Framing With Melamine-Formaldehyde Adhesive and Radio-Frequency Curing

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ABSTRACT

A melamine-formaldehyde adhesive was tested for its ability to bond yellow-poplar and sweetgum veneer laminates to highly porous edges of mixed hardwood flakeboard cores (of the same species) in composite framing. The resin's performance was measured over a practical range of assumed surface characteristics of materials and factory assembly conditions, with the resin cured by radio-frequency generated heat. The effects of filler blends in the adhesive, veneer species, flake size in the cores, adhesive spread rates, adhesive spreading surfaces, and closed assembly times were measured for strength and durability of the bonded joints. The excellence of bond durability was indicated by complete absence of delamination after severe cyclic accelerated aging tests. The excellence of bond strengths was indicated by essentially 100-percent wood failure in every sheared joint. These results were possible at exceptionally low rates of single-surface adhesive spreading over a wide range of closed assembly times on flakeboard cores of different flake size.

Keywords: Yellow-poplar, sweetgum, flakeboard, shear strength, delamination.

Composite framing, a new building material manufactured to the same dimensions as conventional framing lumber, is engineered for structural uses such as wall studs, floor joists, and truss lumber. The composite is of sandwich construction with strips of parallel-laminated veneer bonded to both edges of a flakeboard core. The new material was developed by the USDA Forest Service in cooperation with the Department of Housing and Urban Development and leading manufacturers of wood products.

One of the important tasks in the Forest Service's composite framing program is to investigate new and existing adhesives and bonding techniques for laminating veneer strips to the edges of flakeboard cores. These adhesives must be strong, rigid, and durable enough to enable the framing to support structural loads of long duration under occasionally severe service conditions. The adhesives must be low in total cost and for this particular application curable with radio-frequency (RF) heating. A commercial melamine-formaldehyde (MF) adhesive, though high in resin cost, has the capability of developing highly durable bonds with RF curing at low spread rates.

This study was established to determine if the MF adhesive could effectively bond yellow-poplar and sweetgum veneer laminates to the highly porous edges of flakeboard cores (of the same species) by RF curing the joints over an assumed range of operating conditions of a planned production line. It was of particular interest to determine the lowest adhesive spread rate at which all requirements for bond integrity could be realized within the given range of operating conditions. The study was divided into two experiments. The objective of the first experiment was to determine which of three blends of fillers contributed most to bond integrity. The objective of the second experiment was to determine how effectively the MF adhesive bonded to certain material surfaces within the expected range of factory assembly conditions. The surfaces were two species of veneer laminates and three flakeboard cores. Each core contained a different flake size. Assembly conditions were three adhesive spread rates, two surfaces for spreading, and three closed assembly times.

Performance Requirements

Minimum performance requirements and quality-control tests have been proposed for evaluating strength and durability of adhesive bonds between veneer and core in composite framing (6). The following specifications were based on research in the composite framing program and industry-accepted standards for bonded-wood products.

Properties	Minimum requirements (6)
Shear strength[a]	
Dry	500 lb/in^2
Wet	250 lb/in^2
Wood failure[a]	
Dry	80 percent
Wet	80 percent
Resistance to delamination[b]	<10 percent

[a]Methods of test: ASTM D 1037-78 (3), and USDA Forest Service standard (6).

[b]AITC Test T110 (2).

Materials

Adhesive

The adhesive is an unmodified MF resin that meets the requirements for exterior structural-glued laminated timbers in industry-accepted standards ANSI/AITC A190.1-1983 (1) and ASTM D 2559-82 (4). The resin was supplied as a free-flowing powder that was mixed with water, catalyst, and fillers just before use. The catalyst was ammonium chloride salt that was added to the resin in a ratio of 1:100 parts per hundred (pph), weight basis. A blend of pecan-shell flour and birchwood flour, both 200 mesh, was used as filler. Proportioning of these fillers as blends was studied in Experiment I. For all filler proportions, the melamine-water ratio was 100:60.

Veneer Laminates

Veneer laminates were prepared from 1/4-inch-thick, rotary-cut, yellow-poplar and sweetgum veneers. Four plies of veneer, all of the same species, were laminated with a phenol-resorcinol-formaldehyde (PRF) adhesive so the grain direction in all plies was parallel. Veneers were oriented in the 4-ply laminate so that open lathe checks always faced toward the core. After bonding, the veneer laminates were dried to 5 to 5-1/2 percent moisture content (%MC), ripped into 1-1/2-inch-wide strips, and cut to 12-inch lengths ready for bonding into composite lumber specimens.

Flakeboard Cores

Flakeboard cores were prepared from 3/4-inch-thick, 40 lb/ft^3, homogeneous, mechanically oriented flakeboard with 6-percent phenolic resin binder. The flakes were yellow-poplar and sweetgum mixed in equal proportions by weight. Drum-cut flakes were screened so that three types of flakeboard could be made with each of three size classes of fine particles. Within each board type, flakes were retained on one of three screen sizes: 1/4-, 1/8-, and 1/16-inch mesh. The flakeboards were manufactured to Forest Service specifications in a commercial pilot plant.

The flakeboards were dried to 5 to 5-1/2 %MC while in 3/4-inch thicknesses. Two flakeboards were laminated into 1-1/2-inch thicknesses with a PRF adhesive, ripped into 5-1/4-inch widths, and cut to 12-inch lengths ready for bonding into composite lumber specimens.

EXPERIMENT I

Procedures

Design

The first experiment was designed to determine which of three filler blends might contribute most to developing bonds of highest integrity over a representative range of material surface characteristics and assembly conditions. It is recognized that filler types and loadings can have marked effects on bond integrity and that the degree of those effects results from interactions with surface characteristics, adhesive viscosity, adhesive spread rates, and assembly times. However, to include all such factors in one factorial experiment would require more hardwood flakeboard than was available for this study. In view of these limitations, the following experimental factors and levels of factors were tested in a completely randomized statistical design with factorial arrangement into 3 x 2 = 6 treatment combinations.

Experimental factors	Levels of factors
Filler blends and loadings	1) 70:30 blend of birchwood and pecan-shell flours, 12.8 pph
	2) 50:50 blend of birchwood and pecan-shell flours, 15.6 pph
	3) 30:70 blend of birchwood and pecan-shell flours, 20.4 pph
Surfaces spread	1) Core 2) Veneer
Veneer species	1) Sweetgum
Adhesive spread rate	1) 70 lb/M ft^2
Closed assembly time	1) 6 minutes
Pressure	1) 175 lb/in^2
RF curing conditions	1) 1 minute at 1 ampere and 4.5 kilowatts

Filler Loadings and Viscosity

Pecan-shell flour and birchwood flour were the same particle size (200 mesh) but differed considerably in bulk densities, hence in thickening efficiencies for a given weight. A separate viscosity-filler loading curve was determined for each of the two unblended fillers. Based on these two curves, intermediate curves representing blends of the two fillers were calculated (fig. 1); the amount of filler blend needed to yield a desired viscosity can be read directly from the graph. It should be noted that these curves were based on a 100:60 melamine-water ratio, with viscosity measured at the conditions shown on the graph. At temperatures higher or lower than 23 °C, viscosity will decrease or increase, and filler loadings must be increased or decreased accordingly to maintain a specific viscosity level.

Three adhesives were prepared from the basic 100:60 melamine-water mixture by adding appropriate amounts of each filler blend to yield a viscosity of 1,800 centipoises. As determined from the curves in figure 1, these amounts were 12.8 pph of the 70:30 blend (birchwood/pecan-shell flour), 15.6 pph of the 50:50 blend, and 20.4 pph of the 30:70 blend. To these mixtures, 1.0 pph of ammonium chloride salt was added to accelerate cure.

Apparent viscosities of the adhesive mixtures were measured according to the standard ASTM procedures (5). Measurements were made with a Brookfield Synchro-Lectric Viscometer, Model LTV, with spindle 2.

Specimen Preparation and Testing

Assemblies of composite framing were prepared by bonding a 4-ply veneer laminate of sweetgum to each edge of flakeboard core. One test bondline on one side of an assembly was considered a replicate. One observation of each of five strength properties was taken from the three specimens in each bondline: shear strength and wood failure in both dry and water-saturated conditions, and resistance to delamination. Each treatment combination was replicated four times. Configurations and dimensions of block-shear and delamination specimens are shown in figure 2.

Bonding the 4-ply veneer laminates to each edge of a flakeboard core began by spreading adhesive with a roller on the bonding surfaces according to the spread rates indicated for a given treatment combination. The accuracy of the spread was controlled by automatic weighing of adhesive as it was spread on each bonding surface. Adhesive-spread veneer laminates and cores were assembled and held together under no pressure for prescribed closed assembly times. The adhesive was cured by RF heat from a 13 KVA generator for 1 minute at 1.0 ampere of current with an RF output of 4.5 kilowatts. Pressure was 175 lb/in^2. Before any tests were conducted, specimens were conditioned for 1 week at 38 ± 1 °C and 45 ± 2 percent relative humidity (%RH) to yield an equilibrium moisture content (EMC) of 8 percent.

For tests of shear strength and wood failure under water-saturated conditions, specimens were submerged in tap water in a pressure vessel, applying a vacuum at 25 inches of mercury for 30 minutes, followed by pressure at 75 ± 2 lb/in^2 for 2 hours.

Assigned specimens were subjected to the AITC Test T110 (2) cyclic delamination test. This procedure essentially consisted of repeating two cycles of vacuum-pressure soaking for 2-1/2 hours as just described, with each cycle followed by 15 hours of drying in forced-air at 71 °C. Delamination was measured in the test bondline on both ends of the specimens.

Results and Discussion

Analysis of variance indicated there were no significant differences between strengths of bonds that could be

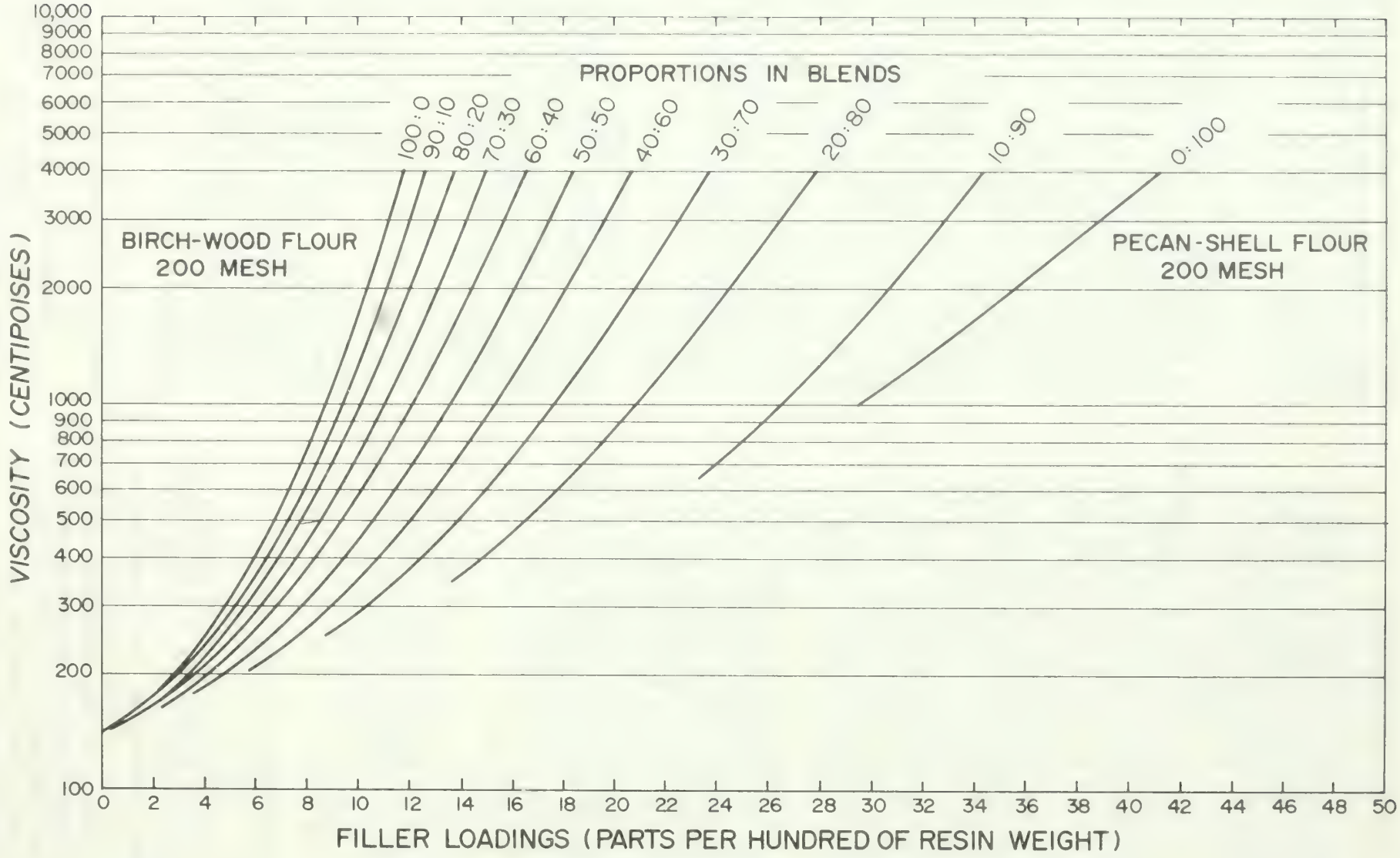

Figure 1.--Viscosity-filler loading curves for blends of birchwood and pecan-shell flours measured in a 100:60 melamine-water solution by a Brookfield Synchro-Lectric Viscometer, Model LVT, spindle 2, 6 rpm, 23 °C.

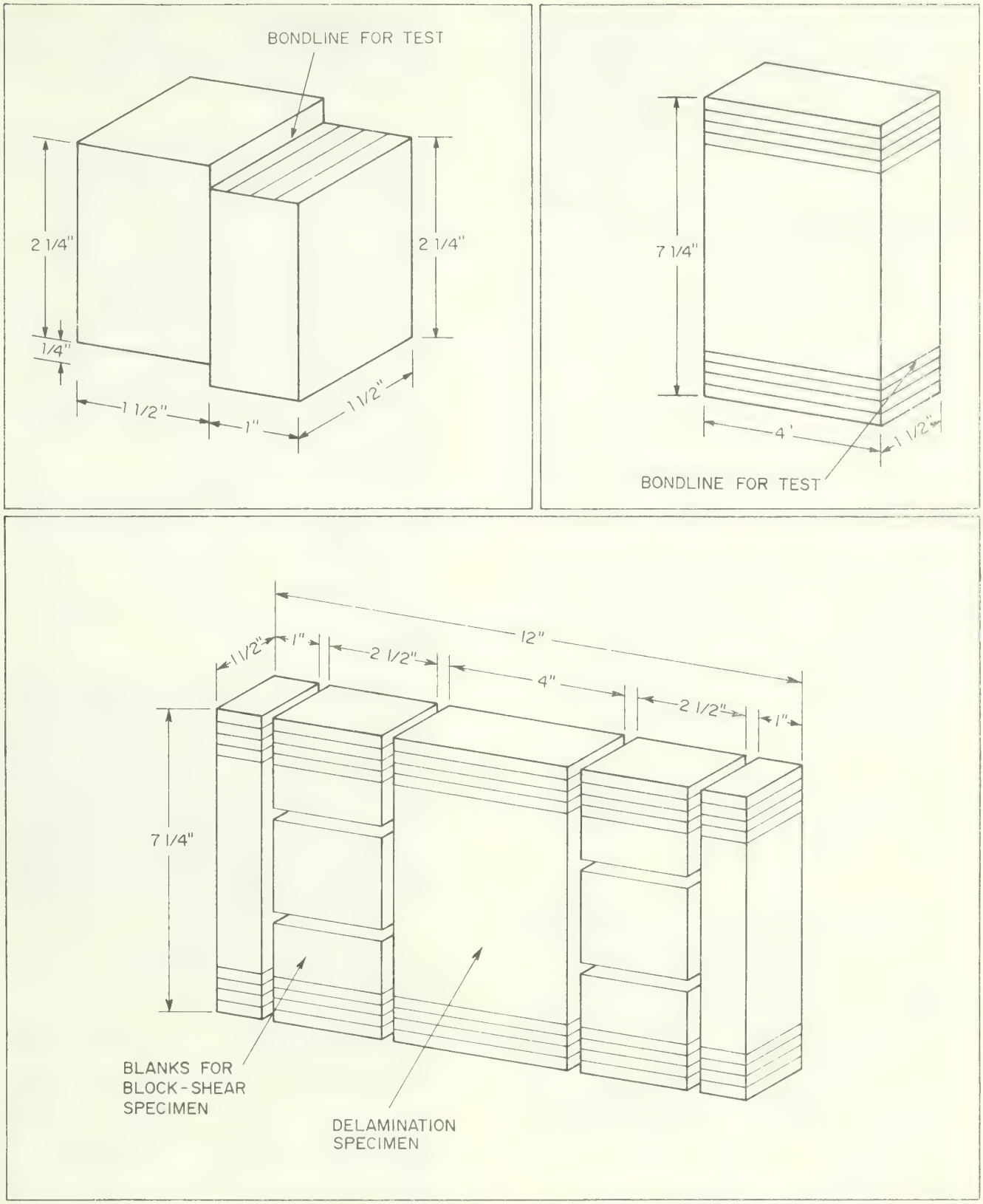

Figure 2.--Configuration and dimensions of block-shear specimen (upper left), cross section for delamination test (upper right), and locations for cutting specimens from a composite assembly (lower).

ascribed to any of the three filler blends or to spreading adhesive on either the veneer or core (table 1). These were the findings from tests of shear strength in both the dry and water-saturated conditions.

Table 1.--Comparison of dry and wet shear strengths as affected by filler blends and surfaces for spreading adhesive

Treatment	Shear strength (lb/in^2)	
	Dry	Wet
30:70 blend	1482	709
70:30 blend	1375	645
50:50 blend	1217	642
Veneer surface	1456	700
Core surface	1260	631

In comparisons of treatment means for a given property, means were not significantly different at $P \geq 0.05$.

Percentage of wood failure, which is a strong indicator of adhesive-bond integrity, clearly indicated that all bonds were as strong as the sweetgum veneer. Essentially, 100-percent wood failure occurred in all joints. Since percentages of wood failure did not vary from 100 percent over any of the treatment combinations, no significant differences could be ascribed to filler blend or to the surface where adhesive was spread.

Resistance to delamination, which tests the ability of the adhesive bond to resist extreme stresses from dimensional changes during wetting and drying, is another property critical to the performance of composite framing. None of the bonds between veneer and core delaminated; for this reason, no significant differences were found among the three filler blends or between the two adhesive spreading surfaces.

Although no statistically significant differences existed between filler blends or spreading surfaces, average strength values (table 1) indicate that stronger bonds developed in both dry and wet tests when adhesive was spread on the veneer. From comparison of strengths among filler blends in both dry and wet tests, it is also clear that bonds were stronger with the adhesive containing the 30:70 blend of birchwood flour and pecan-shell flour. For this reason, the 30:70 blend was considered possibly better, and it was used in Experiment II.

EXPERIMENT II

Procedures

Design

The second experiment was designed to determine how strength properties of melamine bonds between veneer laminates and flakeboard core might be affected by important assembly factors and material surface characteristics which would be likely to occur during manufacture of composite framing. These experimental factors and levels of factors are listed below. This experiment was a randomized block statistical design with 3 x 2 x 2 x 3 factorial arrangement into 36 treatment combinations, in each of three blocks, as follows:

Experimental factors	Levels of factors
Flakes retained on screen	1) 1/4-inch screen 2) 1/8-inch screen 3) 1/16-inch screen
Veneer species	1) Yellow-poplar 2) Sweetgum
Adhesive spread rates	1) 50 lb/M ft^2 2) 70 lb/M ft^2 3) 90 lb/M ft^2
Surfaces spread	1) Core 2) Veneer
Closed assembly times	1) 4 minutes 2) 6 minutes 3) 15 minutes

Filler blend and loading	1) 30:70 blend of birchwood and pecan-shell flours, 20.4 pph
Pressure	1) 175 lb/in^2
RF curing conditions	1) 1 minute at 1 ampere and 4.5 kilowatts

Each treatment combination was replicated four times within each of the three blocks. As in Experiment I, one observation of each of five strength properties was taken from a replicate, and these observations were made from the same types of specimens in a test joint assembly which contained two replicates--one on each edge.

Test joint assemblies were prepared at all combinations of the above experimental factors by the same procedures described in Experiment I. Test specimens were also prepared and tested as previously described.

Results and Discussion

The MF adhesive developed excellent bonds over all 108 combinations of treatments in Experiment II. No delamination occurred in any joint. Furthermore, essentially 100-percent wood failure occurred in every sheared joint, regardless of whether the specimens were tested in the dry or water-saturated condition.

Analysis of variance indicated several of the experimental factors produced significant effects on the shear strengths of bonds, depending on whether the test was made in the dry or wet condition. Mean shear strengths for each experimental factor in dry and wet conditions are shown in table 2, along with indications of whether one or more of these were significantly different from each other within that experimental factor.

The size of flakes retained in flakeboards, as indicated by the 1/4-, 1/8-, and 1/16-inch-mesh screen sizes in table 2, had no significant effect on the strength of bonds in the dry condition. When specimens were sheared in the wet condition, however, bonds made to flakeboards containing 1/16-inch screenings were significantly higher in strength than were bonds to flakeboards made from either 1/8- or 1/4-inch screenings. The difference between the highest and lowest of the mean strengths was an inconsequential 33 lb/in^2. The effect of the 1/16-inch screening (with more fine particles than other sizes) was further evidenced when additional analysis of variance showed this significantly greater strength occurred only when the core surfaces were spread with adhesive, not when the veneer surfaces were spread. With the exception of the just-mentioned instance, screen sizes for flakes were not an important factor in determining strength and durability

Table 2.--Comparisons of dry and wet shear strengths as affected by flake screening sizes, species, adhesive spread rates, surfaces spread, and closed assembly times

Treatments	Shear strengths (lb/in^2) Dry	Wet
SCREEN SIZES		
1/4-inch screen	1392 A	683 B
1/8-inch screen	1383 A	690 B
1/16-inch screen	1368 A	716 A
SPECIES		
Sweetgum	1458 A	744 A
Yellow-poplar	1304 B	671 B
SPREAD RATES		
90 lb/M ft^2	1465 A	744 A
70 lb/M ft^2	1396 B	708 B
50 lb/M ft^2	1282 C	636 C
SURFACES SPREAD		
Veneer	1394 A	699 A
Core	1368 A	693 A
CLOSED ASSEMBLY TIMES		
4 minutes	1411 A	713 A
6 minutes	1374 A	697 AB
15 minutes	1359 A	678 B

In comparisons of treatment means for a given property, means followed by the same letter are not significantly different at $P \geq 0.05$.

of bonds. Where greater strength differences were noted, the effect probably can be attributed to the greater amount of fine particles retained in the flakeboard by the 1/16-inch screening. More fine particles would tend to fill in voids and increase the solid surface area of the flakeboard core edges for better contact with solid veneer surfaces.

Bonds made to sweetgum veneer were significantly stronger than bonds made to yellow-poplar in both dry and wet strength tests (table 2). The difference in strength of joints undoubtedly can be attributed to the inherent differences in shear strength (parallel-to-the-grain) of each species, with sweetgum being the stronger. There were no significant interactions between veneer species and any of the other experimental factors.

The three spread rates produced three significantly different mean shear strengths in both dry and wet conditions. As one would expect, the higher 90 lb/M ft^2 spread rate produced the strongest bonds. Though 183 lb/M ft^2 lower in strength, the 50 lb/M ft^2 spread rate still produced excellent joints, as indicated by essentially 100-percent wood failure in all joints and no delamination in any joints after severe accelerated aging.

There was a significant interaction between adhesive spread rates and the surfaces that were spread in tests of wet shear strength. In subanalysis of adhesive spreads on core surfaces, all spread rates were significantly different from each other. In the subanalysis of spreads on the veneer surfaces, the 90 and 70 lb/M ft^2 spread rates were not significantly different from each other but both were different from the 50 lb/M ft^2 spread rate. Generally, the shear strengths at the 50 lb/M ft^2 spread rate ranged lower when adhesive was spread on the core than when it was spread on veneer. Thus, it seems that some detectable losses in shear strength begin to appear when adhesive is spread on the core, particularly at the 50 lb/M ft^2 spread rate. It should be noted again, however, that bond strength and durability were excellent even at the lowest spread rate.

No significant differences in mean strength values could be attributed to spreading adhesive either on the veneer laminates or flakeboard cores (table 2). The interaction of surfaces with spread rates was the only influence found. It may be slightly more advantageous from a strength standpoint to spread adhesive on veneer laminates than on core, but the practical advantage of being able to spread adhesive on one core rather than two veneer laminates seems to outweigh the small strength advantage.

Closed assembly times of 4, 6, and 15 minutes did not produce any significant differences in bond strengths when specimens were sheared dry. However, in tests of wet strength, the closed assembly time at 4 minutes produced significantly higher strength than at 15 minutes (table 2), but the difference of 35 lb/in^2 between the overall means seems inconsequential from a practical standpoint.

A closer examination of the effects of closed assembly times revealed that significantly lower shear strengths (dry and wet tests) occurred after 15-minute closed assembly than after 4 and 6 minutes when adhesive was spread on veneer surfaces, but not when adhesive was spread on the core. Regardless of the statistical significance given to these differences, mean shear strengths were still higher when adhesive was spread on the veneer rather than the core, even at the 15-minute closed assembly time.

It is perhaps noteworthy that closed assembly times were not significantly different from each other at spread rates of 50 and 70 lb/M ft^2. At 90 lb/M ft^2, however, the 15-minute assembly time was significantly lower than the 4- and 6-minute assembly times in tests of wet shear strength. In tests of dry shear strength, the 15-minute assembly time was significantly lower than the 4-minute assembly time.

Even though these statistical differences appear at the highest spread rate, it is important to point out that mean shear strength increases directly with increasing spread rates. These seemingly conflicting findings only indicate that closed assembly times between 4 and 15 minutes are not the primary influences on joint strengths but that spread rates are.

Conclusions

The MF adhesive, when prepared in a 100:60 melamine-water ratio and mixed with a 30:70 blend of 200-mesh birchwood flour and pecan-shell flour, was capable of producing excellent joints at all combinations of assembly factors and material surfaces tested in these two experiments. The excellence of bond durability was indicated by complete absence of delamination after a severe accelerated aging test. The excellence of bond strengths was indicated by essentially 100-percent wood failure in every sheared joint.

The possible practical and economic implications of these findings to the manufacture of composite framing are:

1. Flakeboard with flakes retained on the 1/16-inch screen (containing largest amounts of fine particles) yielded bonds at least as strong as those of flakeboard with flakes retained on the larger screen sizes.

2. Although bond strengths significantly decreased with decreasing adhesive spread rates, the lowest 50 lb/M ft^2 spread rate still produced acceptable bonds at all test conditions.

3. Whether adhesive was spread on veneer laminate or core was inconsequential in terms of bond strength; however, having capability of spreading two surfaces on one flakeboard core at one time rather than two veneer laminates is of considerable practical consequence.

4. The adhesive was tolerant of closed assembly times between 4 and 15 minutes, even when adhesive was spread on the core.

5. Even though bond strengths were higher for sweetgum than for yellow-poplar veneer, bonds to both species were near the inherent parallel-to-grain shear strength for the respective species.

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Vick, Charles B.

Lamination of composite framing with melamine-formaldehyde adhesive and radio-frequency curing. Res. Pap. SE-254. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1986. 9 pp.

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KEYWORDS: Yellow-poplar veneer, sweetgum veneer, hardwood flakeboard, dry shear strength, wet shear strength, resistance to delamination.

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Weight, Volume, and Physical Properties of Major Hardwood Species in the Piedmont

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ABSTRACT

Weight, volume, and physical properties of trees 1 to 20 inches d.b.h. were determined for red maple, sweetgum, sycamore, yellow-poplar, elm, hickory, chestnut oak, scarlet oak, southern red oak, and white oak in the Piedmont of the Southeastern United States. A total of 772 trees were destructively sampled at 16 locations from Virginia to Alabama. Hard hardwoods, soft hardwoods, and individual species equations are presented for predicting green and dry weight and green volume of the total tree above stump and its components by using d.b.h. and total height, d.b.h. and height to a 4-inch top, d.b.h. and saw-log merchantable height, and d.b.h. alone. Average specific gravity, moisture content, and weight per cubic foot of wood, bark, and wood and bark combined are presented for each species by tree size class and component. Bark percentage is also presented for each species by tree size class and component.

Keywords: Biomass, equations, specific gravity, moisture content, bark percentage, weight per cubic foot.

Piedmont hardwood forests can contribute significantly to supplies of solid wood, fiber, and energy wood through improved utilization and forest management. Few data, however, exist on the weight, volume, and physical properties of the total tree and its components for hardwood species of this region.

To meet this need, a southwide study was initiated by the North Carolina State Hardwood Research Cooperative and the USDA Forest Service. The primary objectives of this study were to determine the amount and distribution of biomass in even-aged fully stocked natural stands and to develop equations for estimating the weight and volume of forest stands, individual trees, and tree components. Secondary objectives were to determine the specific gravity, moisture content, and energy potential of southern hardwoods, and to quantify the distribution of nutrients (N, P, K, Ca, and Mg) in individual trees and soils.

This is part of a southwide study conducted in three geographic regions--the Gulf and Atlantic Coastal Plains, Piedmont, and mid-South. The data collected in the Gulf and Atlantic Coastal Plains have been reported in earlier publications (Clark

and others 1983, 1985; Frederick and others 1983; Gower and others 1983; Messina and others 1983). Mid-South data will be presented in later publications.

This Paper presents tree physical properties and green weight, dry weight and green cubic-volume prediction equations for total tree and tree components of 10 species--red maple (Acer rubrum L.), sweetgum (Liquidambar styraciflua L.), sycamore (Platanus occidentalis L.), yellow-poplar (Liriodendron tulipifera L.), elm species (Ulmus spp.), hickory species (Carya spp.) chestnut oak (Quercus prinus L.), scarlet oak (Q. coccinea Muenchh.), southern red oak (Q. falcata Michx.), and white oak (Q. alba L.) sampled in the Piedmont. These species account for 75 percent of the commercial hardwood volume in the Piedmont regions.

Wood and bark specific gravity, moisture content, bark content, and green weight per cubic foot are presented for the total tree and its components by species and tree size classes. Equations are given for estimating the weight and volume of wood, bark, and foliage, wood and bark and wood only in the total tree, total stem, and the saw-log component of the stem. Ratio equations are also included for estimating total stem and saw-log stem weight or volume to any specified top diameter outside bark (d.o.b.).

Procedure

Field

Sixteen 1/10-acre circular biomass plots were sampled in mixed, even-aged hardwood stands on the Piedmont (fig. 1). Four age classes (10, 20, 40, and 60 years) were sampled on two site types:

> Bottom land. Flood plain areas of major drainage systems and adjacent stream margins, predominantly sandy loam to silt loam surface soils.
>
> Upland (slopes and ridges). Land occupying the large upland interstream divides, predominantly clay to sandy clay loam surface soils.

Age and site combinations were replicated twice. Plots for all ages and site types were randomly located within representative fully stocked stands. Tree data collected on all plots except the 10-year-old plots were used to develop the species equations and properties data reported here. In addition to the fixed-area plots a stratified random sample of three trees per 2-inch class from 6- to 20-inches diameter at breast height (d.b.h.) was sampled at six locations to obtain an even distribution of trees across d.b.h. classes for commercially important species. Figure 1 shows the location of the fixed area and stratified random sample plots.

Data for above-stump total tree and tree component weights and volumes were collected for trees 1 inch d.b.h. and larger. All trees $\geq$ 5.0 inches d.b.h. on the 1/10-acre plots were sampled. At the center of each plot a concentric 1/50-acre subplot was located on which all trees 1.0 to 4.9 inches d.b.h. were sampled.

Means and ranges in age and tree dimensions measured are shown in table 1 for each species and species group sampled. Stump height averaged 0.2 feet for trees 1.0 to 4.9 inches d.b.h., 0.5 feet for trees 5.0 to 10.9 inches d.b.h., and 0.7 feet for trees $\geq$ 11.0 inches d.b.h. Girard form class of the sawtimber-size trees ($\geq$ 11.0 inches d.b.h.) ranged from 66 to 86 and averaged 75 for the soft hardwoods, and ranged from 65 to 91 and averaged 78 for the hard hardwoods.

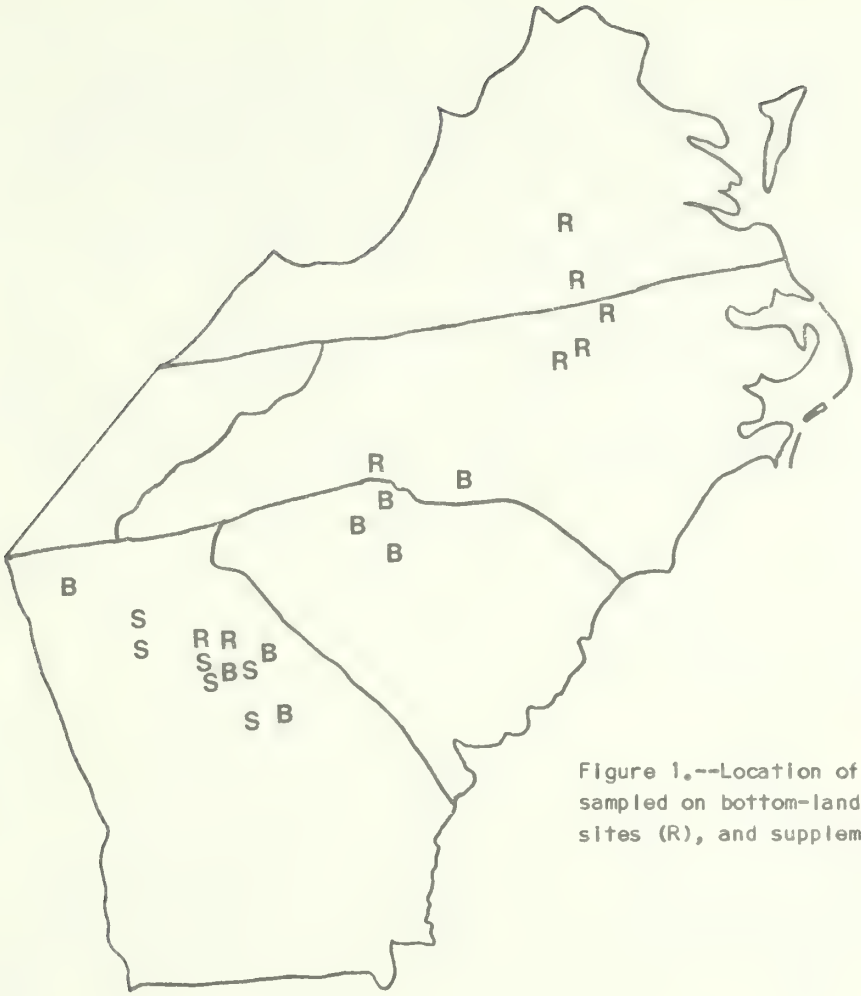

Figure 1.--Location of plots where trees were sampled on bottom-land sites (B), ridge and upland sites (R), and supplemental (S) locations.

Each tree was felled and measured for d.o.b. at 4-foot intervals up the stem. Total height, and height to the saw-log top, 9-, 4-, and 2-inch d.o.b., and base of full live crown were also recorded. Cross-sectional disks of wood and bark were removed from the stem and branches of sample trees for laboratory determination of specific gravity, moisture content, bark percentage, energy value, and nutrient concentration. In all trees $\geq$ 5.0 inches d.b.h, except sawtimber-quality trees (trees $\geq$ 11.0 inches d.b.h. with a minimum of one 16-foot grade 3 log), disks were cut at the butt, d.b.h., and quarter-points to the 4-inch d.o.b. top and at the 2-inch top. In sawtimber trees, disks were removed at the butt, at each saw-log bucking point, and at the stem location where d.o.b. measured 9, 4, and 2 inches. For trees less than 5.0 inches d.b.h., three disks per stem were taken--at stump height and at 25 and 75 percent of total stem height.

The branches of each tree were cut from the stem and weighed in four size categories: extra large ($\geq$ 4.0 inches d.o.b.), large (2.0 to 3.9 inches d.o.b.), medium (0.6 to 1.9 inches d.o.b.), and small ($\leq$ 0.5 inches d.o.b.). Three cross-sectional disks were cut from randomly selected branches in each size category for analysis in the laboratory. Sample branches were randomly selected and weighed with and without foliage to estimate foliage weight. A subsample of the foliage was taken to determine foliage moisture content.

The stem of each tree was weighed by components (saw logs, pulpwood, and topwood) and the branches of each tree were weighted by size category.

Laboratory

Specific gravity was computed on green volume and ovendry weight. Moisture content was computed on ovendry weight after samples were dried to a constant weight at 215 °F. Percentage of bark was determined from disks and based on the green weight of sample disks. Moisture content, specific gravity, and percentage of bark in stem, branches, and total tree were calculated by weighting disk values in proportion to the volume of the component they represented. Weighted values for moisture content were used to convert component green weights to ovendry weight.

By using species diameter inside bark (d.i.b.) prediction equations developed from d.o.b. and d.i.b. stem disk measurements and the d.o.b. and height measurements taken at 4-foot intervals up the stem of each tree, the volume of wood in the stem to the saw-log, 9-inch, 4-inch, 3-inch, 2-inch, and tip were calculated using Smalian's formula. Green weight per cubic foot of stem bark and branch wood and bark were calculated from weighted values for specific gravity and moisture content with the equation:

$$\text{Green weight per cubic foot} = \left[1 + \frac{MC}{100}\right] \cdot (SG) \cdot (C) \qquad (1)$$

where: MC = weighted moisture content in percent

SG = weighted specific gravity

C = 62.4 pounds (weight of water per cubic foot)

Cubic-foot volume of stem bark and branch wood and bark were computed by dividing green component weight by its green weight per cubic foot. Cubic-foot volume of stem wood and bark combined was computed by adding the volume of bark to the volume of wood.

Analysis

Regression equations were developed to predict green and dry weight of wood, bark, and foliage and green volume of wood and bark in the total tree above stump, stem from butt to tip, and saw-log stem. Independent variables were: diameter at breast height (D), total height (Th), saw-log merchantable height (Mh), and height to a 4-inch d.o.b. top (H4).

A logarithmic transformation (base 10) was used to obtain a relatively homogeneous variance, which is assumed in regression analysis. Two equations were developed for the d.b.h., d.b.h. and total height,.and d.b.h. and height to 4-inch top--one for trees < 11.0 inches d.b.h. and one for trees $\geq$ 11.0 inches d.b.h. The 11-inch point was not the optimum point to shift from one equation to the other for all species or tree components, but it was the most desirable from a practical standpoint. Hardwood trees < 11 inches in diameter are classified as sapling or poletimber, and trees $\geq$ 11 inches are classified as sawtimber. The procedure outlined in Draper and Smith (1981) for fitting two linear equations with a known point of intersection was used to develop the following equations:

$$\log Y_p = a + b \log X + E \qquad (2)$$

$$\log Y_s = a + b \log (11^2 H) + c \log (D^2/11^2) + E \qquad (3)$$

where: Y_p = predicted component weight or volume for trees < 11.0 inches d.b.h.

Y_s = predicted component weight or volume for trees $\geq$ 11.0 inches d.b.h.

X = D^2, D^2Th, or D^2H4

H = Th or H4

D = d.b.h.

E = experimental error

a,b,c = regression coefficients

The following model was used for developing regression equations based on d.b.h. and saw-log merchantable height:

$$\log Y = a + b \log X_1 + c \log X_2 + E \quad (4)$$

where: Y = predicted component weight or volume

$X_1 = D^2$

X_2 = Mh

E = experimental error

a,b,c = regression coefficients

When logarithmic estimates are converted back to original units, they are biased downward because the antilogarithm of an estimated mean gives the geometric rather then the arithmetic mean (Cunia 1964). To adjust for this bias, a correction factor was computed and applied to each model by using Baskerville's (1972) procedure. The final equations, including correction factors, were:

$$Y = 10^{a + b \log (D^2) + c \log (Mh) + (S^2_{y.x} \log_e 10)/2} \quad (5)$$

$$Y_p = 10^{a + b \log (D^2H) + (S^2_{y.x} \log_e 10)/2} \quad (6)$$

$$Y_s = 10^{a + b \log (11^2H) + c \log (D^2/11^2) + (S^2_{y.x} \log_e 10)/2} \quad (7)$$

Equations (5), (6), and (7) can be simplified to:

$$Y = a' (D^2)^b (Mh)^c \quad (8)$$

$$Y_p = a' (D^2H)^b \quad (9)$$

$$Y_s = a'' (D^2)^b (H)^c \quad (10)$$

where: $a' = 10^{a + (S^2_{y.x} \log_e 10)/2}$

$a'' = a' (11^2)^b - c$

$S^2_{y.x}$ = error mean square from regression analysis

Comparison of average deviations (actual minus predicted) by d.b.h. classes and the sums of the squared deviations for the single log-log equation and segmented log-log equation showed that segmented log-log equations (9) and (10) gave the best results for the d.b.h., d.b.h. and total height, and d.b.h. and height to 4-inch top independent variable combinations (Clark and others 1984). Equations (9) and (10) are more complex than a single equation, but the improved accuracy justified their use.

The following exponential ratio equation was used to estimate the proportion of predicted total-stem weight or volume to a specified top d.o.b.:

$$Y_R = e^a (d^b D^c) \quad (11)$$

where: Y_R = ratio of stem weight or volume to top d.o.b. to predicted total stem

d = specified stem top diameter in inches

D = tree diameter at breast height in inches

a,b,c = regression coefficients

e = base of natural log = 2.71828

The exponential ratio model shown below was developed to estimate a ratio for expanding saw-log stem weight or volume to any d.o.b. top above the saw-log top.

$$Y_R = e^a \left[(Mh)^b \left(\left(1 - \left(\frac{d}{.78D} \right)^2 \right)^2 \right)^c \right] \quad (12)$$

where: Y_R = ratio of stem weight or volume to top d.o.b. to saw-log stem

Mh = saw-log merchantable height in feet

d = specified top diameter in inches

D = tree diameter at breast height in inches

.78 = constant based on average form class

a,b,c = regression coefficients

e = 2.71828 (base of natural log)

Results

Physical Properties of Sample Trees

The average specific gravity of wood and bark by tree component is shown in table 2 for individual species, soft hardwoods, hard hardwoods, and all trees combined. The average total-tree wood specific gravity of the soft hardwood species was 0.493 for saplings (1.0 to 4.9 inches d.b.h.), 0.467 for poletimber

(5.0 to 10.9 inches d.b.h.), and 0.465 for sawtimber (≥ 11.0 inches d.b.h.) compared with hard hardwood species, which averaged 0.623 for saplings, 0.608 for poletimber, and 0.618 for sawtimber. Yellow-poplar had the lowest average total-tree wood specific gravity and red maple the highest for the soft hardwoods group. In the hard hardwoods group, elm had the lowest average total-tree wood specific gravity and white oak the highest.

Specific gravity of bark was lower than that of the wood for the soft hardwood species except red maple and sycamore, and for the hard hardwood species except scarlet oak and southern red oak (table 2).

The average moisture content of wood and bark by tree component and size class is shown in table 3 for the species and species groups sampled. Total-tree wood moisture content for the soft hardwoods averaged 97 percent for saplings, 102 percent for poletimber, and 105 percent for sawtimber compared with the hard hardwoods, which averaged 70 percent for saplings, 69 percent for poletimber, and 71 percent for sawtimber. In the soft hardwoods group, sycamore had the highest average total-tree wood moisture content compared with red maple, which had the lowest. In the hard hardwoods group, hickory had the lowest total-tree wood moisture content compared with scarlet oak, which had the highest.

Total-tree average bark moisture content for the soft hardwoods was 107 percent in saplings, 108 percent in poletimber, and 102 percent in sawtimber compared with 102 percent for saplings, 67 percent for poletimber, and 65 percent for sawtimber for the hard hardwood species (table 3).

Table 4 shows the average proportion of bark in the tree, based on green weight of wood and bark, by tree component and size class, for the species sampled. The percentage of stem weight in bark decreased as stem d.b.h. increased. Sycamore had a significantly lower proportion of its stem weight in bark than any of the other species. Yellow-poplar had the highest bark percentage of the soft hardwoods and hickory and chestnut oak had the highest for the hard hardwoods.

The average green weight per cubic foot of wood, bark, and wood and bark combined, by tree component, for saplings, poletimber, and sawtimber are shown in table 5. Because of the soft hardwood and hard hardwood species grouping, the average range of species green weight for cubic foot of wood for the two groups is similar--54 to 66 pounds for the soft hardwoods and 57 to 68 pounds for the hard hardwoods. This is caused by the relatively high moisture content of sweetgum and sycamore in the soft hardwoods group and the low moisture content of hickory in the hard hardwoods group. The average green weight per cubic foot of wood for the soft hardwood species was 60 pounds for poletimber and 61 pounds for sawtimber compared with 64 pounds for poletimber and 66 pounds for sawtimber hard hardwoods.

The average green weight of wood and bark per cubic foot of wood by tree component for saplings, poletimber, and sawtimber-size trees is shown in table 6. The weight of wood and bark per cubic-foot volume of wood is a useful factor for estimating the volume of wood in a tree or its components when weight of wood and bark is known or for estimating green weight of wood and bark when volume of wood is known. The green weight of wood and bark per cubic foot of wood for the total tree averaged 71 pounds for poletimber and 70 pounds for sawtimber soft hardwoods compared with 79 pounds for poletimber and sawtimber hard hardwoods.

The average green weight of wood and bark per cubic foot of wood was highest for branches and decreased with increasing stem diameter (table 6).

Prediction Equations

A series of equations was developed to predict total-tree and tree component weight and volume for each species, the soft hardwood and hard hardwood groups, and all species combined. Equations were developed for predicting the green and dry weight of wood, bark and foliage, wood and bark combined, and wood alone in the above-stump total tree. Stem equations were developed for estimating the green and dry weight of wood and bark combined and wood alone for the total stem. Volume equations were also developed for wood and bark combined and wood alone in the above-stump total tree and total stem.

Since tree height is measured to different top limits by various organizations, equations were developed by using diameter (D) alone and in combination with total height (Th), height to 4-inch top (H4), and merchantable height (Mh) as independent variables. Equation (9) was used to estimate the weight and volume of the total tree and stem for trees 1.0 to 10.9 inches d.b.h., and equation (10) was used for trees $\geq$ 11.0 inches d.b.h. when D alone, D and Th, or D and H4 were the independent variables.

Equation (8) was used to estimate weight and volume of the total tree and saw-log merchantable stem for trees $\geq$ 11.0 inches d.b.h. when D and Mh were the independent variables. Equations based on D and Mh were developed only for species sampled sufficiently in the sawtimber diameter classes. Equations were developed for the soft hardwoods, hard hardwoods, and all species, and for sweetgum, sycamore, yellow-poplar, scarlet oak, southern red oak, and white oak.

Equation (11) was used to estimate the proportion of total-stem weight or volume in the stem to any d.o.b. top when stem weight or volume was estimated with D, D and Th, or D and H4 as the independent variables. Equation (12) was used to estimate a ratio for expanding estimated saw-log merchantable-stem weight or volume to any d.o.b. top above the saw-log top when D and Mh were the independent variables.

Equations that use D with Th or D with H4 fit the existing total-tree and total-stem weight and volume data well, based on the criteria of mean square error and absolute deviation of observed from predicted. Equations that use D and Mh fit existing saw-log merchantable-stem weight and volume data well. When average tree height and stem taper are similar to those of our sample trees, the equations with D alone will result in good estimates of the tree weight and volume. When average tree height by d.b.h. class is different from the sample trees, however, the equations that include a height variable should be applied directly or used to develop local weight-volume tables based on D alone.

Regression coefficients for estimating weight and volume are listed below, by independent variable and table number:

Independent variable	Weight	Volume
D alone	tables 7, 8	tables 9, 10
D and Th	tables 11, 12	tables 13, 14
D and H4	tables 15, 16	tables 17, 18
D and Mh	tables 19, 20	tables 21, 22

In addition to the regression coefficients, tables 7 through 22 contain the coefficients of determination and standard error ($\log_{10}$) for each equation.

Regression coefficients for estimating the proportion of the total-stem weight and volume in the stem to a specified d.o.b. top are given in tables 23 and 24. Table 23 contains coefficients for estimating ratios for stem green and dry weight of wood and bark combined and wood only, and table 24 contains the coefficients for stem volume of wood and bark combined and wood alone. Equation coefficients for expanding estimated saw-log merchantable-stem weight and volume are shown in tables 25 and 26, respectively.

How to Use Prediction Equations

The following examples illustrate how to use the equations in tables 7 through 26 to estimate the weight or volume of the total tree and its components.

This tabulation presents the tree data needed to estimate weight and volume when d.b.h. and Th are measured and equations (9) and (10) are used:

Example of trees < 11.0 inches d.b.h.

D = 10.0 inches

Th = 70 feet

Example of trees $\geq$ 11.0 inches

D = 14.0 inches

Th = 90 feet

To estimate total-stem wood and bark green weight (Y_{STEMWB}) of a soft hardwood with these dimensions, the following equations would be selected from table 12 and solved as follows:

Trees < 11.0 inches d.b.h.--use equation (9)

$$Y_{STEMWB} = a' (D^2Th)^b$$

$$= 0.19535 ((10^2) (70))^{0.95420}$$

$$= 0.19535 (7000)^{0.95420}$$

$$= 0.19535 (4,666.51)$$

$$Y_{STEMWB} = 912 \text{ pounds}$$

Trees $\geq$ 11 inches d.b.h.--use equation (10)

$$Y_{STEMWB} = a'' (D^2)^b (Th)^c$$

$$= 0.13963 (14^2)^{1.02422} (90)^{0.95420}$$

$$= 0.13963 (196)^{1.02422} (90)^{0.95420}$$

$$= 0.13963 (222.73) (73.24)$$

$$Y_{STEMWB} = 2,278 \text{ pounds}$$

The same mathematical procedure shown above would be used to solve equations (9) or (10) for any of the tree component equations in tables 7 through 22.

To estimate the proportion of total-stem green weight of wood and bark in the stem of a 10-inch d.b.h. tree to a 4-inch d.o.b. top (Y_R), the following soft hardwood ratio regression coefficients would be selected from table 23 and solved by using equation (11) as shown below. The same equation is used for all size trees.

$$Y_R = e^{a} (d)^{b} (D)^{c}$$

$$= 2.71828 \left[-1.73265 \ (4)^{4.21073} \ (10)^{-4.28793} \right]$$

$$= 2.71828 \left[-1.73265 \ (342.86) \ (0.0000515) \right]$$

$$= 2.71828^{-0.03059}$$

$$Y_R = 0.970$$

Stem weight to 4-inch top = (Y_{STEMWB}) (Y_R)

= 912 (0.970)

Stem weight to 4-inch top = 885 pounds

The procedure shown above can be used to estimate the proportion of total stem in the stem to any d.o.b. top by substituting for d in equation (11).

The following tabulation shows the tree data needed to estimate weights and volumes when d.b.h. and Mh are measured and equation (8) is used.

D = 14.0 inches d.b.h.

Mh = 2.0 logs

To use equation (8), Mh must be in feet, thus:

Mh = 33.1 feet = (2.0 logs) (16.3 ft/log) + (0.5 ft for stump)

To estimate the green weight of wood and bark in the saw-log merchantable stem (Y_{SAWWB}) of a soft hardwood tree, by using equation (8) the following regression coefficients would be selected from table 20 and solved as follows:

$$Y_{SAWWB} = a' \ (D^2)^{b} \ (Mh)^{c}$$

$$= 0.67595 \ (14^2)^{0.89328} \ (33.1)^{0.85866}$$

$$= 0.67595 \ (111.59) \ (20.18)$$

$$Y_{SAWWB} = 1{,}522 \text{ pounds}$$

The same mathematical procedure shown above would be used to solve equation (8) for any sawtimber tree component equation in tables 19 through 22.

To estimate a ratio (Y_R) for expanding estimated saw-log merchantable-stem green weight of wood and bark of the previous tree to weight to a 4-inch d.o.b. top, the following soft hardwood ratio equation would be selected from table 25 and solved by using equation (12) as shown below:

$$Y_R = e^a \left[(Mh)^b \left(\left(1-\left(\frac{d}{.780}\right)^2\right)^2 \right)^c \right]$$

$$= 2.71828^{34.56311} \left[(33.1)^{-1.33687} \left(\left(1-\left(\frac{4}{.78(14)}\right)^2\right)^2 \right)^{0.34540} \right]$$

$$= 2.71828^{34.56311(0.009294)(0.90527)}$$

$$= 2.71828^{0.29080}$$

$$Y_R = 1.337$$

Stem weight to 4-inch top = $(Y_{SAWWB})\ (Y_R)$

= 1,522 (1.337)

Stem weight to 4-inch top = 2,035 pounds

The tree components predicted by using the equations provided can be used to calculate additional tree components. For example, to estimate the weight or volume of the crown (branches and topwood) subtract estimated weight of the stem to a specified d.o.b. top from total-tree weight of wood and bark. The weight or volume of bark alone can also be estimated by subtracting component weight or volume of wood from wood and bark.

Similar-size trees may vary in weight and volume because of differences in crown size, stem taper, and weight per cubic foot. Therefore, these equations should be applied only to trees growing in natural, fully stocked stands with tree dimensions and weight per cubic foot similar to the tree sampled.

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TABLES

Table 1.--Mean and range of tree age and measurements, by species and tree size class

Tree size class (inches)	Sample trees	Age		D.b.h.		Total height		Height to 4-inch d.o.b. top		Height to saw-log merchantable top		D.o.b. at saw-log merchantable top	
		Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
	Number			Inches		Feet						Inches	
SOFT HARDWOODS													
1.0- 4.9	108	18	3-40	2.8	1.0- 4.9	33	12- 58	10	2-20	--	--	--	--
5.0-10.9	203	36	12-72	7.4	5.0-10.9	61	40- 96	34	10-69	--	--	--	--
>11.0	124	52	33-83	14.8	11.0-20.7	88	70-115	68	47-90	39	8-67	10.0	8.0-14.5
All trees	435	35	3-83	8.4	1.0-20.7	62	12-115	46	2-90	39	8-67	10.0	8.0-14.5
RED MAPLE													
1.0- 4.9	8	23	9-37	2.4	1.0- 4.9	33	15- 57	20	20-20	--	--	--	--
5.0-10.9	16	42	22-72	7.3	5.2-10.7	61	45- 74	36	19-53	--	--	--	--
>11.0	8	59	48-65	13.5	11.2-15.9	75	72- 80	53	48-56	18	17-22	11.1	9.2-14.3
All trees	32	41	9-72	7.6	1.0-15.9	58	15- 80	40	19-56	18	17-22	11.1	9.2-14.3
SWEETGUM													
1.0- 4.9	61	17	6-40	2.8	1.0- 4.9	34	13- 58	7	6- 8	--	--	--	--
5.0-10.9	119	35	16-61	7.2	5.0-10.8	62	42- 96	33	10-69	--	--	--	--
>11.0	56	49	33-83	14.6	11.1-20.7	89	71-107	68	50-88	39	11-62	9.6	8.1-14.4
All trees	236	34	6-83	7.8	1.0-20.7	61	13-107	43	6-88	39	11-62	9.6	8.1-14.4
SYCAMORE													
1.0- 4.9	4	10	3- 16	3.5	1.9- 4.9	44	30- 53	13	9-16	--	--	--	--
5.0-10.9	10	19	12- 32	7.6	5.1- 9.4	58	48- 66	36	16-48	--	--	--	--
>11.0	15	44	34- 59	15.0	11.0-19.5	97	71-115	76	47-90	44	18-64	9.8	9.0-13.0
All trees	29	31	3- 59	10.9	1.9-19.5	76	30-115	56	9-90	44	18-64	9.8	9.0-13.0
YELLOW-POPLAR													
1.0- 4.0	3	32	31- 33	3.5	2.7- 4.6	41	33- 46	--	--	--	--	--	--
5.0-10.9	35	41	15- 63	7.8	5.2-10.5	64	42- 85	40	17-63	--	--	--	--
>11.0	40	61	35- 83	15.3	11.1-20.3	86	70-107	68	54-89	42	17-67	10.0	8.0-14.5
All trees	78	50	15- 83	11.5	2.7-20.3	74	33-107	55	17-89	42	17-67	10.0	8.0-14.5
HARD HARDWOODS													
1.0- 4.9	73	20	7- 39	2.3	1.0- 4.4	27	12- 53	8	6- 9	--	--	--	--
5.0-10.9	165	44	12-105	7.3	5.0-10.9	59	29- 90	34	8-67	--	--	--	--
>11.0	99	71	33-145	14.6	11.0-20.9	77	52- 97	57	34-79	31	14-52	11.6	8.3-18.5
All Trees	338	45	7-145	8.4	1.0-20.9	57	12- 97	42	6-79	31	14-52	11.6	8.3-18.5
ELM													
1.0- 4.0	8	22	13-30	2.0	1.0- 4.8	23	13- 52	12	12-12	--	--	--	--
5.0-10.9	7	39	22-60	8.0	5.8-10.8	61	43- 77	35	12-54	--	--	--	--
>11.0	1	42	42-42	11.2	11.2-11.2	71	71- 71	52	52-52	8	8- 8	10.4	10.4-10.4
All trees	16	29	13-60	5.2	1.0-11.2	43	13- 77	34	12-54	8	8- 8	10.4	10.4-10.4

Continued

Table 1.--Mean and range of tree age and measurements, by species and tree size class--Continued

Tree size class (inches)	Sample trees	Age		D.b.h.		Total height		Height to 4-inch d.o.b. top		Height to saw-log merchantable top		D.o.b. at saw-log merchantable top	
		Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
	Number			Inches				Feet				Inches	
HICKORY													
1.0- 4.9	4	19	11- 25	2.2	1.5- 3.9	24	17- 36	--	--	--	--	--	--
5.0-10.9	8	77	45-105	8.2	5.2-10.8	56	45- 68	36	15-50	--	--	--	--
>11.0	10	125	90-145	14.8	11.5-18.5	80	68- 97	57	38-78	27	17-41	13.3	9.0-17.8
All Trees	22	82	11-145	10.1	1.5-18.5	61	17- 97	47	15-78	27	17-41	13.3	9.0-17.8
CHESTNUT OAK													
1.0- 4.9	12	16	7- 39	2.2	1.2- 4.1	30	12- 53	6	6- 6	--	--	--	--
5.0-10.9	22	46	18- 65	6.7	5.0-10.8	56	29- 70	30	12-54	--	--	--	--
>11.0	3	85	83- 90	13.8	12.9-14.6	62	59- 63	46	45-50	25	24-26	11.1	9.4-12.0
All trees	37	41	7- 90	5.8	1.2-14.6	48	12- 70	31	6-54	25	24-26	11.1	9.4-12.0
SCARLET OAK													
5.0-10.9	15	43	29- 56	7.8	5.1-10.9	59	48- 68	35	18-46	--	--	--	--
>11.0	17	62	33- 86	14.2	11.2-18.8	66	53- 72	48	34-57	27	17-41	11.9	9.0-18.5
All trees	32	50	29- 86	11.2	5.1-18.8	63	48- 72	42	18-57	27	17-41	11.9	9.0-18.5
SOUTHERN RED OAK													
1.0- 4.9	2	16	12- 19	2.8	2.3- 3.2	36	30- 43	--	--	--	--	--	--
5.0-10.9	22	22	15- 32	6.9	5.1-10.0	55	41- 81	30	8-58	--	--	--	--
>11.0	24	63	38- 78	14.7	11.0-18.8	80	68- 88	61	49-70	33	14-46	12.0	9.0-18.0
All trees	48	42	12- 78	10.6	2.3-18.8	67	30- 88	46	8-70	33	14-46	12.0	9.0-18.0
WHITE OAK													
1.0- 4.9	15	28	20- 35	3.2	2.1- 4.4	34	15- 45	9	9- 9	--	--	--	--
5.0-10.9	56	43	12- 66	7.5	5.1-10.5	58	47- 76	34	17-50	--	--	--	--
>11.0	39	59	42- 90	15.1	11.2-20.9	77	52- 95	57	34-76	31	15-43	11.4	8.3-15.6
All trees	110	44	12- 90	9.6	2.1-20.9	61	15- 95	43	9-76	31	15-43	11.4	8.3-15.6
ALL SPECIES													
1.0- 4.9	181	19	3- 40	2.6	1.0- 4.9	31	12- 58	10	2-20	--	--	--	--
5.0-10.9	368	39	12-105	7.4	5.0-10.9	60	29- 96	34	8-69	--	--	--	--
>11.0	223	59	33-145	14.7	11.0-20.9	83	52-115	63	34-90	35	8-66	10.7	8.0-18.5
All trees	772	39	3-145	8.4	1.0-20.9	60	12-115	44	2-90	35	8-66	10.7	8.0-18.5

Table 2.--Average specific gravity of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Piedmont

Tree size class (inches)	Average and standard deviation						
		Stem					
	Total tree	Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	Branches
SOFT HARDWOODS							
Wood							
1.0- 4.9	0.492 ± 0.060	--	--	--	--	0.492 ± 0.062	0.493 ± 0.060
5.0-10.9	0.467 ± 0.053	--	--	0.466 ± 0.055	0.470 ± 0.055	0.465 ± 0.054	0.480 ± 0.048
≥11.0	0.465 ± 0.035	0.462 ± 0.039	0.473 ± 0.036	0.463 ± 0.037	0.478 ± 0.033	0.464 ± 0.036	0.475 ± 0.030
Bark							
1.0- 4.9	0.394 ± 0.085	--	--	--	--	0.386 ± 0.096	0.427 ± 0.057
5.0-10.9	0.407 ± 0.067	--	--	0.395 ± 0.083	0.427 ± 0.057	0.401 ± 0.076	0.424 ± 0.057
≥11.0	0.440 ± 0.073	0.440 ± 0.086	0.454 ± 0.078	0.445 ± 0.082	0.454 ± 0.065	0.445 ± 0.081	0.429 ± 0.068
Wood and Bark							
1.0- 4.9	0.475 ± 0.054	--	--	--	--	0.473 ± 0.056	0.474 ± 0.053
5.0-10.9	0.458 ± 0.048	--	--	0.453 ± 0.050	0.461 ± 0.047	0.457 ± 0.049	0.462 ± 0.046
≥11.0	0.461 ± 0.034	0.458 ± 0.039	0.467 ± 0.035	0.459 ± 0.036	0.471 ± 0.032	0.460 ± 0.036	0.459 ± 0.033
RED MAPLE							
Wood							
1.0- 4.9	0.468 ± 0.032	--	--	--	--	0.473 ± 0.033	0.459 ± 0.035
5.0-10.9	0.463 ± 0.019	--	--	0.462 ± 0.020	0.464 ± 0.026	0.462 ± 0.020	0.473 ± 0.028
≥11.0	0.524 ± 0.037	0.536 ± 0.035	0.514 ± 0.036	0.526 ± 0.036	0.526 ± 0.040	0.526 ± 0.036	0.519 ± 0.042
Bark							
1.0- 4.9	0.467 ± 0.036	--	--	--	--	0.485 ± 0.029	0.434 ± 0.062
5.0-10.9	0.499 ± 0.042	--	--	0.511 ± 0.046	0.490 ± 0.032	0.506 ± 0.044	0.478 ± 0.041
≥11.0	0.512 ± 0.039	0.547 ± 0.045	0.553 ± 0.041	0.551 ± 0.039	0.514 ± 0.045	0.550 ± 0.039	0.453 ± 0.050
Wood and Bark							
1.0- 4.9	0.453 ± 0.027	--	--	--	--	0.475 ± 0.031	0.423 ± 0.046
5.0-10.9	0.468 ± 0.017	--	--	0.466 ± 0.020	0.468 ± 0.024	0.467 ± 0.018	0.474 ± 0.020
≥11.0	0.523 ± 0.035	0.537 ± 0.033	0.518 ± 0.033	0.528 ± 0.034	0.524 ± 0.034	0.529 ± 0.033	0.502 ± 0.035

Continued

Table 2.--Average specific gravity of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Piedmont--Continued

Tree size class (inches)	Average and standard deviation						
		Stem					
	Total tree	Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	Branches
				SWEETGUM			
				Wood			
1.0- 4.9	0.472 ± 0.027	--	--	--	--	0.470 ± 0.029	0.479 ± 0.033
5.0-10.9	0.468 ± 0.028	--	--	0.468 ± 0.032	0.468 ± 0.027	0.466 ± 0.030	0.481 ± 0.025
≥11.0	0.479 ± 0.022	0.476 ± 0.024	0.488 ± 0.026	0.477 ± 0.023	0.490 ± 0.022	0.478 ± 0.023	0.490 ± 0.017
				Bark			
1.0- 4.9	0.338 ± 0.050	--	--	--	--	0.325 ± 0.054	0.410 ± 0.051
5.0-10.9	0.378 ± 0.055	--	--	0.353 ± 0.069	0.418 ± 0.054	0.366 ± 0.063	0.422 ± 0.035
≥11.0	0.441 ± 0.053	0.429 ± 0.071	0.451 ± 0.061	0.440 ± 0.064	0.462 ± 0.038	0.440 ± 0.063	0.440 ± 0.034
				Wood and Bark			
1.0- 4.9	0.455 ± 0.021	--	--	--	--	0.446 ± 0.026	0.457 ± 0.029
5.0-10.9	0.455 ± 0.027	--	--	0.448 ± 0.031	0.458 ± 0.027	0.454 ± 0.029	0.463 ± 0.024
≥11.0	0.475 ± 0.019	0.471 ± 0.022	0.483 ± 0.025	0.473 ± 0.021	0.484 ± 0.020	0.474 ± 0.021	0.477 ± 0.017
				SYCAMORE			
				Wood			
1.0- 4.9	0.423 ± 0.036	--	--	--	--	0.423 ± 0.037	0.440 ± 0.054
5.0-10.9	0.459 ± 0.020	--	--	0.457 ± 0.020	0.459 ± 0.023	0.457 ± 0.020	0.468 ± 0.030
≥11.0	0.447 ± 0.025	0.450 ± 0.030	0.438 ± 0.017	0.446 ± 0.026	0.451 ± 0.030	0.447 ± 0.025	0.450 ± 0.027
				Bark			
1.0- 4.9	0.466 ± 0.043	--	--	--	--	0.467 ± 0.053	0.460 ± 0.043
5.0-10.9	0.504 ± 0.028	--	--	0.517 ± 0.029	0.470 ± 0.044	0.510 ± 0.027	0.488 ± 0.043
≥11.0	0.566 ± 0.034	0.581 ± 0.036	0.575 ± 0.048	0.576 ± 0.039	0.558 ± 0.043	0.576 ± 0.039	0.545 ± 0.048
				Wood and Bark			
1.0- 4.9	0.426 ± 0.036	--	--	--	--	0.425 ± 0.037	0.445 ± 0.050
5.0-10.9	0.463 ± 0.019	--	--	0.460 ± 0.019	0.460 ± 0.022	0.460 ± 0.019	0.471 ± 0.027
≥11.0	0.454 ± 0.023	0.454 ± 0.029	0.444 ± 0.017	0.451 ± 0.025	0.461 ± 0.028	0.452 ± 0.024	0.459 ± 0.026
				YELLOW-POPLAR			
				Wood			
1.0- 4.9	0.450 ± 0.033	--	--	--	--	0.452 ± 0.038	0.431 ± 0.020
5.0-10.9	0.406 ± 0.027	--	--	0.404 ± 0.031	0.417 ± 0.033	0.403 ± 0.030	0.426 ± 0.020
≥11.0	0.444 ± 0.028	0.439 ± 0.031	0.459 ± 0.036	0.442 ± 0.031	0.467 ± 0.030	0.442 ± 0.031	0.457 ± 0.019

Continued

Table 2.--Average specific gravity of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Piedmont--Continued

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
				Bark			
1.0- 4.9	0.400 ± 0.014	--	--	--	--	0.402 ± 0.018	0.393 ± 0.002
5.0-10.9	0.387 ± 0.023	--	--	0.395 ± 0.027	0.389 ± 0.029	0.394 ± 0.026	0.353 ± 0.033
≥11.0	0.381 ± 0.030	0.382 ± 0.035	0.398 ± 0.032	0.384 ± 0.034	0.394 ± 0.036	0.384 ± 0.034	0.364 ± 0.038
				Wood and Bark			
1.0- 4.9	0.440 ± 0.030	--	--	--	--	0.441 ± 0.028	0.420 ± 0.019
5.0-10.9	0.403 ± 0.024	--	--	0.402 ± 0.028	0.411 ± 0.028	0.401 ± 0.026	0.403 ± 0.017
≥11.0	0.434 ± 0.026	0.430 ± 0.029	0.447 ± 0.031	0.433 ± 0.029	0.448 ± 0.026	0.434 ± 0.029	0.429 ± 0.024
				HARD HARDWOODS			
				Wood			
1.0- 4.9	0.623 ± 0.036	--	--	--	--	0.625 ± 0.036	0.609 ± 0.049
5.0-10.9	0.608 ± 0.045	--	--	0.606 ± 0.047	0.608 ± 0.047	0.605 ± 0.046	0.618 ± 0.049
≥11.0	0.618 ± 0.032	0.602 ± 0.039	0.627 ± 0.038	0.605 ± 0.038	0.654 ± 0.034	0.606 ± 0.038	0.654 ± 0.029
				Bark			
1.0- 4.9	0.432 ± 0.128	--	--	--	--	0.440 ± 0.145	0.399 ± 0.092
5.0-10.9	0.555 ± 0.057	--	--	0.563 ± 0.069	0.556 ± 0.064	0.563 ± 0.068	0.530 ± 0.056
≥11.0	0.593 ± 0.057	0.608 ± 0.066	0.604 ± 0.067	0.607 ± 0.066	0.578 ± 0.060	0.606 ± 0.066	0.573 ± 0.061
				Wood and Bark			
1.0- 4.9	0.587 ± 0.032	--	--	--	--	0.592 ± 0.030	0.530 ± 0.065
5.0-10.9	0.598 ± 0.037	--	--	0.598 ± 0.040	0.594 ± 0.038	0.599 ± 0.039	0.588 ± 0.041
≥11.0	0.616 ± 0.024	0.603 ± 0.031	0.623 ± 0.029	0.606 ± 0.029	0.633 ± 0.030	0.607 ± 0.030	0.631 ± 0.032
				ELM			
				Wood			
1.0- 4.9	0.604 ± 0.050	--	--	--	--	0.606 ± 0.055	0.586 ± 0.047
5.0-10.9	0.566 ± 0.034	--	--	0.570 ± 0.044	0.558 ± 0.035	0.566 ± 0.038	0.572 ± 0.028
				Bark			
1.0- 4.9	0.382 ± 0.041	--	--	--	--	0.351 ± 0.035	0.440 ± 0.049
5.0-10.9	0.418 ± 0.042	--	--	0.405 ± 0.037	0.401 ± 0.044	0.404 ± 0.038	0.439 ± 0.063
				Wood and Bark			
1.0- 4.9	0.579 ± 0.047	--	--	--	--	0.560 ± 0.040	0.571 ± 0.021
5.0-10.9	0.547 ± 0.030	--	--	0.551 ± 0.039	0.522 ± 0.030	0.550 ± 0.033	0.537 ± 0.034

Continued

Table 2.--Average specific gravity of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Piedmont--Continued

Tree size class (inches)	Average and standard deviation						
		Stem					
	Total tree	Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	Branches
HICKORY							
				Wood			
1.0- 4.9	0.621 ± 0.011	--	--	--	--	0.631 ± 0.011	0.539 ± 0.042
5.0-10.9	0.618 ± 0.037	--	--	0.625 ± 0.039	0.624 ± 0.039	0.624 ± 0.038	0.591 ± 0.044
≥11.0	0.641 ± 0.036	0.632 ± 0.037	0.668 ± 0.036	0.638 ± 0.036	0.673 ± 0.040	0.639 ± 0.036	0.647 ± 0.043
				Bark			
1.0- 4.9	0.565 ± 0.038	--	--	--	--	0.571 ± 0.039	0.515 ± 0.083
5.0-10.9	0.502 ± 0.044	--	--	0.530 ± 0.029	0.505 ± 0.050	0.530 ± 0.030	0.444 ± 0.049
≥11.0	0.530 ± 0.047	0.555 ± 0.050	0.556 ± 0.033	0.554 ± 0.045	0.514 ± 0.049	0.553 ± 0.044	0.488 ± 0.062
				Wood and Bark			
1.0- 4.9	0.592 ± 0.000	--	--	--	--	0.613 ± 0.018	0.467 ± 0.000
5.0-10.9	0.591 ± 0.034	--	--	0.603 ± 0.033	0.588 ± 0.033	0.602 ± 0.033	0.532 ± 0.039
≥11.0	0.621 ± 0.034	0.620 ± 0.037	0.645 ± 0.033	0.624 ± 0.036	0.631 ± 0.036	0.625 ± 0.036	0.596 ± 0.046
CHESTNUT OAK							
				Wood			
1.0- 4.9	0.617 ± 0.032	--	--	--	--	0.623 ± 0.030	0.579 ± 0.053
5.0-10.9	0.618 ± 0.023	--	--	0.623 ± 0.020	0.609 ± 0.037	0.620 ± 0.023	0.602 ± 0.035
≥11.0	0.615 ± 0.026	0.608 ± 0.036	0.626 ± 0.033	0.616 ± 0.035	0.618 ± 0.029	0.616 ± 0.034	0.595 ± 0.041
				Bark			
1.0- 4.9	0.506 ± 0.036	--	--	--	--	0.509 ± 0.042	0.484 ± 0.020
5.0-10.9	0.549 ± 0.023	--	--	0.567 ± 0.026	0.538 ± 0.032	0.563 ± 0.024	0.477 ± 0.034
≥11.0	0.550 ± 0.022	0.581 ± 0.009	0.564 ± 0.013	0.573 ± 0.004	0.526 ± 0.024	0.572 ± 0.004	0.504 ± 0.040
				Wood and Bark			
1.0- 4.9	0.591 ± 0.029	--	--	--	--	0.595 ± 0.028	0.544 ± 0.039
5.0-10.9	0.603 ± 0.020	--	--	0.611 ± 0.017	0.590 ± 0.031	0.609 ± 0.021	0.553 ± 0.035
≥11.0	0.601 ± 0.018	0.602 ± 0.031	0.612 ± 0.022	0.607 ± 0.027	0.591 ± 0.019	0.608 ± 0.027	0.566 ± 0.033

Continued

Table 2.--Average specific gravity of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Piedmont--Continued

Tree size class (inches)	Average and standard deviation						
		Stem					
	Total tree	Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	Branches
SCARLET OAK							
Wood							
5.0-10.9	0.602 ± 0.018	--	--	0.590 ± 0.021	0.612 ± 0.021	0.591 ± 0.020	0.645 ± 0.008
≥11.0	0.592 ± 0.030	0.569 ± 0.040	0.599 ± 0.036	0.573 ± 0.038	0.636 ± 0.033	0.573 ± 0.038	0.641 ± 0.015
Bark							
5.0-10.9	0.602 ± 0.030	--	--	0.620 ± 0.035	0.584 ± 0.043	0.615 ± 0.037	0.569 ± 0.010
≥11.0	0.621 ± 0.018	0.649 ± 0.029	0.647 ± 0.030	0.648 ± 0.029	0.615 ± 0.021	0.647 ± 0.029	0.587 ± 0.015
Wood and Bark							
5.0-10.9	0.602 ± 0.014	--	--	0.594 ± 0.019	0.606 ± 0.017	0.594 ± 0.017	0.622 ± 0.009
≥11.0	0.597 ± 0.025	0.579 ± 0.036	0.606 ± 0.032	0.582 ± 0.035	0.631 ± 0.026	0.583 ± 0.035	0.628 ± 0.010
SOUTHERN RED OAK							
Wood							
1.0- 4.9	0.634 ± 0.021	--	--	--	--	0.633 ± 0.018	0.637 ± 0.033
5.0-10.9	0.606 ± 0.036	--	--	0.604 ± 0.041	0.614 ± 0.026	0.601 ± 0.039	0.648 ± 0.018
≥11.0	0.596 ± 0.020	0.572 ± 0.023	0.604 ± 0.024	0.576 ± 0.021	0.653 ± 0.032	0.577 ± 0.021	0.651 ± 0.028
Bark							
1.0- 4.9	0.605 ± 0.088	--	--	--	--	0.626 ± 0.112	0.520 ± 0.001
5.0-10.9	0.621 ± 0.052	--	--	0.632 ± 0.063	0.636 ± 0.051	0.638 ± 0.059	0.574 ± 0.048
≥11.0	0.665 ± 0.034	0.680 ± 0.046	0.675 ± 0.045	0.681 ± 0.044	0.639 ± 0.042	0.680 ± 0.044	0.636 ± 0.027
Wood and Bark							
1.0- 4.9	0.625 ± 0.038	--	--	--	--	0.627 ± 0.041	0.599 ± 0.023
5.0-10.9	0.609 ± 0.030	--	--	0.608 ± 0.035	0.619 ± 0.026	0.608 ± 0.034	0.624 ± 0.019
≥11.0	0.610 ± 0.018	0.588 ± 0.019	0.618 ± 0.022	0.593 ± 0.017	0.649 ± 0.032	0.593 ± 0.017	0.647 ± 0.023
WHITE OAK							
Wood							
1.0- 4.9	0.627 ± 0.024	--	--	--	--	0.628 ± 0.024	0.607 ± 0.043
5.0-10.9	0.636 ± 0.029	--	--	0.635 ± 0.031	0.635 ± 0.032	0.634 ± 0.030	0.639 ± 0.038
≥11.0	0.636 ± 0.021	0.621 ± 0.027	0.643 ± 0.030	0.623 ± 0.027	0.664 ± 0.029	0.624 ± 0.027	0.671 ± 0.015

Continued

Table 2.--Average specific gravity of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Piedmont--Continued

Tree size class (inches)	Average and standard deviation						
		Stem					
	Total tree	Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	Branches
				Bark			
1.0- 4.9	0.464 ± 0.038	--	--	--	--	0.463 ± 0.038	0.489 ± 0.052
5.0-10.9	0.520 ± 0.035	--	--	0.511 ± 0.045	0.522 ± 0.037	0.511 ± 0.042	0.538 ± 0.052
≥11.0	0.568 ± 0.028	0.574 ± 0.045	0.570 ± 0.049	0.572 ± 0.045	0.557 ± 0.038	0.572 ± 0.045	0.566 ± 0.050
				Wood and Bark			
1.0- 4.9	--	--	--	--	--	0.595 ± 0.027	--
5.0-10.9	0.617 ± 0.025	--	--	0.615 ± 0.029	0.607 ± 0.025	0.617 ± 0.028	0.607 ± 0.017
≥11.0	0.627 ± 0.018	0.616 ± 0.024	0.632 ± 0.026	0.617 ± 0.023	0.633 ± 0.025	0.619 ± 0.023	0.642 ± 0.023
				ALL SPECIES			
				Wood			
1.0- 4.9	0.534 ± 0.081	--	--	--	--	0.534 ± 0.083	0.530 ± 0.079
5.0-10.9	0.525 ± 0.085	--	--	0.524 ± 0.086	0.527 ± 0.086	0.523 ± 0.086	0.537 ± 0.084
≥11.0	0.532 ± 0.083	0.524 ± 0.080	0.541 ± 0.085	0.526 ± 0.080	0.556 ± 0.093	0.526 ± 0.080	0.553 ± 0.094
				Bark			
1.0- 4.9	0.406 ± 0.102	--	--	--	--	0.403 ± 0.116	0.418 ± 0.071
5.0-10.9	0.468 ± 0.097	--	--	0.464 ± 0.114	0.480 ± 0.087	0.468 ± 0.108	0.468 ± 0.077
≥11.0	0.508 ± 0.101	0.514 ± 0.114	0.520 ± 0.104	0.516 ± 0.110	0.508 ± 0.088	0.516 ± 0.110	0.492 ± 0.097
				Wood and Bark			
1.0- 4.9	0.507 ± 0.071	--	--	--	--	0.511 ± 0.074	0.490 ± 0.062
5.0-10.9	0.515 ± 0.082	--	--	0.513 ± 0.085	0.516 ± 0.079	0.515 ± 0.083	0.514 ± 0.076
≥11.0	0.529 ± 0.083	0.522 ± 0.080	0.536 ± 0.084	0.524 ± 0.080	0.542 ± 0.086	0.525 ± 0.080	0.535 ± 0.091

Table 3.--Average moisture content of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Piedmont

Tree size class (inches)	Average and standard deviation						
		Stem					
	Total tree	Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	Branches
	Percent						
SOFT HARDWOODS							
Wood							
1.0- 4.9	97 ± 22.4	--	--	--	--	98 ± 23.3	96 ± 20.8
5.0-10.9	102 ± 22.4	--	--	103 ± 24.0	99 ± 22.3	103 ± 23.8	101 ± 18.1
≥11.0	105 ± 18.4	107 ± 22.0	100 ± 19.7	106 ± 20.8	98 ± 14.7	106 ± 20.6	101 ± 11.2
Bark							
1.0- 4.9	107 ± 23.8	--	--	--	--	106 ± 25.5	118 ± 29.1
5.0-10.9	108 ± 24.5	--	--	103 ± 28.0	117 ± 28.9	105 ± 27.4	127 ± 30.2
≥11.0	102 ± 22.5	95 ± 27.3	97 ± 28.4	94 ± 26.1	118 ± 30.3	95 ± 26.0	124 ± 27.6
Wood and Bark							
1.0- 4.9	102 ± 19.4	--	--	--	--	99 ± 22.1	105 ± 20.4
5.0-10.9	103 ± 20.4	--	--	102 ± 21.5	102 ± 20.0	103 ± 21.4	109 ± 20.1
≥11.0	104 ± 15.5	106 ± 19.1	99 ± 16.8	104 ± 17.9	102 ± 14.3	105 ± 17.8	108 ± 14.1
RED MAPLE							
Wood							
1.0- 4.9	77 ± 7.9	--	--	--	--	77 ± 7.5	79 ± 9.9
5.0-10.9	77 ± 14.1	--	--	76 ± 15.8	81 ± 13.4	76 ± 15.5	85 ± 10.4
≥11.0	66 ± 5.9	63 ± 6.1	63 ± 4.6	63 ± 5.4	70 ± 5.7	63 ± 5.3	76 ± 8.2
Bark							
1.0- 4.9	97 ± 7.8	--	--	--	--	95 ± 9.6	99 ± 16.9
5.0-10.9	94 ± 13.2	--	--	91 ± 14.2	101 ± 10.0	93 ± 13.4	94 ± 20.9
≥11.0	102 ± 9.3	93 ± 19.3	95 ± 7.3	92 ± 11.3	108 ± 15.7	93 ± 11.4	117 ± 12.8
Wood and Bark							
1.0- 4.9	86 ± 2.7	--	--	--	--	80 ± 6.7	89 ± 7.0
5.0-10.9	79 ± 13.1	--	--	77 ± 14.2	83 ± 11.7	78 ± 14.0	87 ± 11.8
≥11.0	70 ± 5.7	65 ± 5.1	67 ± 4.4	66 ± 4.8	76 ± 6.5	67 ± 4.7	86 ± 6.5
SWEETGUM							
Wood							
1.0- 4.9	112 ± 10.0	--	--	--	--	113 ± 11.1	106 ± 17.4
5.0-10.9	113 ± 11.7	--	--	114 ± 13.0	108 ± 14.6	113 ± 12.8	106 ± 10.2
≥11.0	111 ± 10.9	115 ± 13.1	104 ± 12.9	113 ± 12.1	97 ± 9.2	112 ± 12.0	101 ± 9.1
Bark							
1.0- 4.9	117 ± 23.3	--	--	--	--	116 ± 25.1	132 ± 27.2
5.0-10.9	108 ± 22.3	--	--	102 ± 27.7	115 ± 22.5	104 ± 26.7	128 ± 15.5
≥11.0	92 ± 19.6	86 ± 26.6	85 ± 24.5	83 ± 23.0	106 ± 22.9	84 ± 22.9	116 ± 16.0

Continued

Table 3.--Average moisture content of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Piedmont--Continued

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Percent						
Wood and Bark							
1.0- 4.9	86 ± 2.7	--	--	--	--	80 ± 6.7	89 ± 7.0
5.0-10.9	79 ± 13.1	--	--	77 ± 14.2	83 ± 11.7	78 ± 14.0	87 ± 11.8
≥11.0	70 ± 5.7	65 ± 5.1	67 ± 4.4	66 ± 4.8	76 ± 6.5	67 ± 4.7	86 ± 6.5
SWEETGUM							
Wood							
1.0- 4.9	112 ± 10.0	--	--	--	--	113 ± 11.1	106 ± 17.4
5.0-10.9	113 ± 11.7	--	--	114 ± 13.0	108 ± 14.6	113 ± 12.8	106 ± 10.2
≥11.0	111 ± 10.9	115 ± 13.1	104 ± 12.9	113 ± 12.1	97 ± 9.2	112 ± 12.0	101 ± 9.1
Bark							
1.0- 4.9	117 ± 23.3	--	--	--	--	116 ± 25.1	132 ± 27.2
5.0-10.9	108 ± 22.3	--	--	102 ± 27.7	115 ± 22.5	104 ± 26.7	128 ± 15.5
≥11.0	92 ± 19.6	86 ± 26.6	85 ± 24.5	83 ± 23.0	106 ± 22.9	84 ± 22.9	116 ± 16.0
Wood and Bark							
1.0- 4.9	112 ± 8.8	--	--	--	--	114 ± 11.1	112 ± 19.1
5.0-10.9	111 ± 10.7	--	--	111 ± 11.8	109 ± 13.0	112 ± 11.9	113 ± 8.6
≥11.0	108 ± 8.6	112 ± 10.9	100 ± 10.0	109 ± 9.7	98 ± 9.4	110 ± 10.0	105 ± 9.3
SYCAMORE							
Wood							
1.0- 4.9	121 ± 20.7	--	--	--	--	121 ± 21.3	118 ± 14.9
5.0-10.9	123 ± 13.7	--	--	125 ± 14.5	121 ± 19.5	124 ± 14.9	116 ± 14.4
≥11.0	122 ± 7.6	125 ± 11.6	127 ± 8.7	126 ± 9.7	119 ± 7.5	125 ± 9.2	106 ± 6.3
Bark							
1.0- 4.9	116 ± 32.9	--	--	--	--	116 ± 39.4	121 ± 30.7
5.0-10.9	120 ± 15.8	--	--	116 ± 20.2	145 ± 30.6	120 ± 19.4	122 ± 13.2
≥11.0	92 ± 6.7	90 ± 9.7	93 ± 10.7	91 ± 9.9	96 ± 23.4	91 ± 9.7	94 ± 9.1
Wood and Bark							
1.0- 4.9	121 ± 21.4	--	--	--	--	121 ± 22.2	118 ± 12.0
5.0-10.9	122 ± 13.3	--	--	124 ± 14.4	123 ± 18.9	124 ± 14.7	117 ± 12.2
≥11.0	120 ± 7.0	124 ± 11.3	126 ± 8.4	124 ± 9.4	117 ± 7.0	124 ± 8.9	104 ± 5.9
YELLOW-POPLAR							
Wood							
1.0- 4.9	101 ± 18.9	--	--	--	--	101 ± 19.6	97 ± 5.7
5.0-10.9	99 ± 21.3	--	--	99 ± 23.9	93 ± 20.4	98 ± 23.4	109 ± 10.5
≥11.0	97 ± 17.0	96 ± 19.4	91 ± 15.7	96 ± 19.0	97 ± 13.5	96 ± 18.9	106 ± 7.9

Continued

Table 3.--Average moisture content of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Piedmont--Continued

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Percent						
Bark							
1.0- 4.9	102 ± 35.6	--	--	--	--	98 ± 38.9	115 ± 33.2
5.0-10.9	67 ± 12.3	--	--	64 ± 14.5	70 ± 13.8	64 ± 13.9	78 ± 14.2
≥11.0	65 ± 12.9	61 ± 15.5	62 ± 15.0	61 ± 15.4	68 ± 15.3	61 ± 15.3	71 ± 13.9
Wood and Bark							
1.0- 4.9	77 ± 13.9	--	--	--	--	75 ± 12.9	85 ± 13.8
5.0-10.9	68 ± 7.1	--	--	69 ± 8.4	69 ± 7.8	69 ± 8.2	70 ± 7.5
≥11.0	69 ± 6.3	73 ± 8.6	67 ± 7.2	72 ± 8.3	64 ± 6.4	72 ± 8.2	63 ± 5.8
ELM							
Wood							
1.0- 4.9	66 ± 5.9	--	--	--	--	66 ± 7.8	67 ± 4.6
5.0-10.9	76 ± 6.9	--	--	78 ± 8.6	75 ± 5.6	78 ± 7.7	70 ± 7.5
Bark							
1.0- 4.9	93 ± 10.0	--	--	--	--	94 ± 12.5	92 ± 16.5
5.0-10.9	87 ± 15.0	--	--	91 ± 24.5	89 ± 20.5	90 ± 21.9	82 ± 10.7
Wood and Bark							
1.0- 4.9	71 ± 4.5	--	--	--	--	71 ± 6.0	72 ± 5.7
5.0-10.9	77 ± 6.8	--	--	79 ± 8.2	78 ± 6.6	79 ± 7.1	73 ± 8.3
HICKORY							
Wood							
1.0- 4.9	61 ± 5.5	--	--	--	--	60 ± 5.9	65 ± 5.3
5.0-10.9	56 ± 6.8	--	--	54 ± 5.6	54 ± 5.4	54 ± 5.4	63 ± 9.4
≥11.0	58 ± 7.8	63 ± 8.7	52 ± 4.0	61 ± 8.1	51 ± 4.1	61 ± 8.1	52 ± 8.5
Bark							
1.0- 4.9	75 ± 14.5	--	--	--	--	75 ± 14.6	78 ± 16.6
5.0-10.9	85 ± 17.2	--	--	78 ± 15.2	88 ± 20.0	78 ± 14.7	99 ± 15.2
≥11.0	81 ± 15.4	76 ± 16.1	75 ± 12.8	76 ± 14.9	88 ± 21.2	76 ± 14.7	89 ± 20.7
Wood and Bark							
1.0- 4.9	74 ± 0.0	--	--	--	--	64 ± 8.4	79 ± 0.0
5.0-10.9	63 ± 8.8	--	--	59 ± 6.4	64 ± 8.9	59 ± 6.3	77 ± 12.0
≥11.0	62 ± 7.9	65 ± 9.5	57 ± 5.3	64 ± 8.8	60 ± 6.5	63 ± 8.7	64 ± 11.4

Continued

Table 3.--Average moisture content of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Piedmont--Continued

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Percent						
CHESTNUT OAK							
Wood							
1.0- 4.9	63 ± 5.3	--	--	--	--	62 ± 5.7	69 ± 5.2
5.0-10.9	63 ± 4.6	--	--	63 ± 4.8	63 ± 5.3	63 ± 4.8	63 ± 3.2
≥11.0	69 ± 3.6	72 ± 4.0	68 ± 2.4	70 ± 3.3	64 ± 3.2	70 ± 3.3	66 ± 4.9
Bark							
1.0- 4.9	80 ± 16.8	--	--	--	--	76 ± 18.9	100 ± 10.6
5.0-10.9	57 ± 6.9	--	--	49 ± 6.1	63 ± 10.8	51 ± 5.3	90 ± 10.8
≥11.0	62 ± 8.9	53 ± 5.9	56 ± 11.6	54 ± 8.7	74 ± 7.1	55 ± 8.6	78 ± 7.0
Wood and Bark							
1.0- 4.9	67 ± 8.1	--	--	--	--	65 ± 8.7	81 ± 5.6
5.0-10.9	61 ± 3.4	--	--	60 ± 3.6	62 ± 5.3	60 ± 3.7	73 ± 5.2
≥11.0	67 ± 0.8	68 ± 1.8	64 ± 1.3	67 ± 0.5	67 ± 2.1	67 ± 0.8	70 ± 4.8
SCARLET OAK							
Wood							
5.0-10.9	74 ± 3.5	--	--	78 ± 5.7	70 ± 2.6	77 ± 5.4	62 ± 0.8
≥11.0	79 ± 6.8	85 ± 9.0	77 ± 7.8	85 ± 8.5	67 ± 3.6	84 ± 8.5	65 ± 3.2
Bark							
5.0-10.9	65 ± 5.1	--	--	67 ± 8.9	70 ± 8.8	67 ± 8.5	64 ± 2.3
≥11.0	63 ± 5.6	62 ± 8.1	62 ± 7.8	62 ± 7.6	65 ± 7.3	62 ± 7.5	64 ± 5.3
Wood and Bark							
5.0-10.9	72 ± 3.4	--	--	76 ± 5.6	70 ± 2.6	76 ± 5.4	63 ± 1.4
≥11.0	76 ± 5.9	82 ± 8.1	75 ± 6.7	82 ± 7.6	67 ± 3.1	82 ± 7.6	65 ± 2.9
SOUTHERN RED OAK							
Wood							
1.0- 4.9	68 ± 5.7	--	--	--	--	69 ± 5.3	64 ± 7.8
5.0-10.9	71 ± 4.6	--	--	72 ± 5.0	70 ± 6.4	72 ± 4.8	62 ± 5.0
≥11.0	74 ± 4.4	81 ± 6.1	73 ± 3.3	80 ± 5.3	64 ± 4.2	79 ± 5.3	60 ± 5.7
Bark							
1.0- 4.9	70 ± 23.1	--	--	--	--	69 ± 26.4	73 ± 7.6
5.0-10.9	61 ± 11.9	--	--	58 ± 12.5	61 ± 10.3	57 ± 11.4	72 ± 12.3
≥11.0	53 ± 8.4	50 ± 12.9	49 ± 7.0	50 ± 11.6	56 ± 5.9	50 ± 11.4	58 ± 7.4

Continued

Table 3.--Average moisture content of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Piedmont--Continued

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Percent						
Wood and Bark							
1.0- 4.9	69 ± 10.0	--	--	--	--	69 ± 10.2	67 ± 7.9
5.0-10.9	68 ± 5.4	--	--	69 ± 5.6	68 ± 6.7	69 ± 5.5	66 ± 7.4
≥11.0	70 ± 4.1	76 ± 5.3	69 ± 2.8	75 ± 4.7	62 ± 4.2	75 ± 4.6	60 ± 5.5
WHITE OAK							
Wood							
1.0- 4.9	64 ± 5.8	--	--	--	--	63 ± 6.0	69 ± 4.7
5.0-10.9	65 ± 3.8	--	--	66 ± 5.0	64 ± 4.0	66 ± 4.9	61 ± 3.4
≥11.0	68 ± 4.6	72 ± 6.4	66 ± 5.8	71 ± 6.3	63 ± 6.1	71 ± 6.2	61 ± 2.1
Bark							
1.0- 4.9	92 ± 15.5	--	--	--	--	91 ± 16.4	100 ± 15.4
5.0-10.9	70 ± 13.8	--	--	68 ± 20.1	71 ± 16.6	68 ± 19.4	78 ± 5.3
≥11.0	67 ± 10.2	62 ± 16.6	64 ± 16.7	63 ± 16.6	69 ± 13.9	63 ± 16.4	74 ± 6.6
Wood and Bark							
1.0- 4.9	70 ± 6.9	--	--	--	--	69 ± 7.7	76 ± 6.1
5.0-10.9	65 ± 4.7	--	---	66 ± 6.3	66 ± 6.0	66 ± 6.0	66 ± 2.5
≥11.0	68 ± 4.8	71 ± 6.7	66 ± 6.3	70 ± 6.6	65 ± 7.5	70 ± 6.5	64 ± 2.8
ALL SPECIES							
Wood							
1.0- 4.9	89 ± 23.1	--	--	--	—	89 ± 24.1	88 ± 20.9
5.0-10.9	89 ± 24.4	--	--	89 ± 25.3	86 ± 23.5	89 ± 25.1	86 ± 22.9
≥11.0	90 ± 22.4	93 ± 23.8	86 ± 22.2	92 ± 22.9	82 ± 20.8	92 ± 22.9	84 ± 22.0
Bark							
1.0- 4.9	105 ± 28.0	--	--	--	--	103 ± 30.4	117 ± 30.3
5.0-10.9	91 ± 28.7	--	--	87 ± 30.3	98 ± 33.4	88 ± 30.3	107 ± 34.5
≥11.0	85 ± 26.3	80 ± 28.5	82 ± 29.4	80 ± 27.4	96 ± 34.9	80 ± 27.4	101 ± 35.0
Wood and Bark							
1.0- 4.9	94 ± 21.2	--	--	--	--	92 ± 22.8	99 ± 20.7
5.0-10.9	89 ± 23.4	--	--	89 ± 24.0	88 ± 23.0	89 ± 24.0	93 ± 25.1
≥11.0	89 ± 21.2	91 ± 22.4	85 ± 20.8	90 ± 21.5	86 ± 22.0	91 ± 21.6	89 ± 24.7

Table 4.--Average proportion of wood and bark green weight in bark, by tree component and size class, for hardwood species in the Piedmont

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Percent						
SOFT HARDWOODS							
1.0- 4.9	19 ± 5.5	--	--	--	--	17 ± 5.1	30 ± 6.2
5.0-10.9	15 ± 3.4	--	--	12 ± 3.2	20 ± 5.0	13 ± 3.4	29 ± 5.4
≥11.0	13 ± 4.1	10 ± 3.9	15 ± 5.5	11 ± 3.9	24 ± 8.4	11 ± 3.9	25 ± 6.5
RED MAPLE							
1.0- 4.9	20 ± 4.0	--	--	--	--	18 ± 3.0	28 ± 4.7
5.0-10.9	14 ± 1.4	--	--	11 ± 1.6	17 ± 2.4	12 ± 1.7	26 ± 2.9
≥11.0	15 ± 1.4	11 ± 1.3	13 ± 1.0	11 ± 1.2	18 ± 1.8	11 ± 1.2	25 ± 2.6
SWEETGUM							
1.0- 4.9	19 ± 4.3	--	--	--	--	17 ± 4.0	31 ± 4.8
5.0-10.9	15 ± 2.3	--	--	12 ± 2.1	20 ± 4.0	13 ± 2.4	30 ± 3.5
≥11.0	12 ± 1.9	9 ± 1.8	15 ± 3.6	10 ± 1.7	26 ± 8.3	10 ± 1.7	26 ± 3.8
SYCAMORE							
1.0- 4.9	6 ± 1.4	--	--	--	--	6 ± 1.0	30 ± 7.7
5.0-10.9	7 ± 1.3	--	--	5 ± 1.0	8 ± 1.4	6 ± 1.2	17 ± 4.7
≥11.0	5 ± 0.7	4 ± 0.6	5 ± 1.0	4 ± 0.6	9 ± 1.9	4 ± 0.6	11 ± 2.7
YELLOW-POPLAR							
1.0- 4.9	28 ± 1.6	--	--	--	--	25 ± 2.4	51 ± 8.7
5.0-10.9	18 ± 2.6	--	--	16 ± 2.2	24 ± 3.2	17 ± 2.4	31 ± 4.7
≥11.0	17 ± 1.8	14 ± 2.3	19 ± 3.4	15 ± 2.2	27 ± 3.3	15 ± 2.2	29 ± 3.4
HARD HARDWOODS							
1.0- 4.9	20 ± 4.9	--	--	--	--	19 ± 5.3	26 ± 6.7
5.0-10.9	18 ± 4.0	--	--	15 ± 4.2	22 ± 4.7	16 ± 4.1	29 ± 5.2
≥11.0	16 ± 3.3	12 ± 3.6	16 ± 4.2	13 ± 3.6	26 ± 4.2	13 ± 3.6	25 ± 3.6
ELM							
1.0- 4.9	20 ± 5.1	--	--	--	--	18 ± 4.6	28 ± 7.5
5.0-10.9	13 ± 3.6	--	--	8 ± 2.9	19 ± 1.2	10 ± 3.4	23 ± 4.1
HICKORY							
1.0- 4.9	31 ± 1.9	--	--	--	--	30 ± 1.7	37 ± 2.8
5.0-10.9	27 ± 2.9	--	--	24 ± 2.4	32 ± 3.0	24 ± 2.5	37 ± 3.8
≥11.0	21 ± 3.6	17 ± 4.2	20 ± 3.6	17 ± 4.0	27 ± 4.8	17 ± 4.0	30 ± 4.8
CHESTNUT OAK							
1.0- 4.9	27 ± 3.7	--	--	--	--	25 ± 3.4	38 ± 5.5
5.0-10.9	22 ± 3.0	--	--	19 ± 3.4	25 ± 3.6	20 ± 3.5	37 ± 4.7
≥11.0	22 ± 2.4	18 ± 2.4	21 ± 2.8	19 ± 2.5	29 ± 3.4	19 ± 2.5	32 ± 6.1

Continued

Table 4.--Average proportion of wood and bark green weight in bark, by tree component and size class, for hardwood species in the Piedmont--Continued

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Percent						
SCARLET OAK							
5.0-10.9	17 ± 1.1	--	--	13 ± 1.7	19 ± 1.5	14 ± 1.9	28 ± 3.4
≥11.0	16 ± 1.3	13 ± 1.3	14 ± 2.7	13 ± 1.3	22 ± 3.3	13 ± 1.3	22 ± 1.4
SOUTHERN RED OAK							
1.0- 4.9	24 ± 7.6	--	--	--	--	23 ± 8.7	30 ± 3.0
5.0-10.9	20 ± 2.0	--	--	18 ± 2.5	22 ± 3.2	19 ± 2.1	29 ± 4.2
≥11.0	18 ± 2.3	15 ± 2.4	19 ± 3.8	16 ± 2.7	27 ± 2.1	16 ± 2.7	25 ± 1.9
WHITE OAK							
1.0- 4.9	22 ± 5.5	--	--	--	--	20 ± 5.6	37 ± 3.2
5.0-10.9	17 ± 1.5	--	--	13 ± 1.3	22 ± 3.0	14 ± 1.5	28 ± 2.0
≥11.0	14 ± 1.5	10 ± 1.4	13 ± 2.3	10 ± 1.3	27 ± 3.8	10 ± 1.3	24 ± 2.2
ALL SPECIES							
1.0- 4.9	19 ± 5.4	--	--	--	--	18 ± 5.3	29 ± 6.6
5.0-10.9	16 ± 4.0	--	--	13 ± 4.9	21 ± 3.9	14 ± 3.9	29 ± 5.3
≥11.0	15 ± 4.0	11 ± 3.9	15± 5.0	12 ± 3.9	24 ± 6.9	12 ± 3.9	25 ± 5.4

Table 5.--Average green weight per cubic foot of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Piedmont

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Pounds per cubic foot						
SOFT HARDWOODS							
Wood							
1.0- 4.9	60 ± 5.9	--	--	--	--	60 ± 6.0	59 ± 7.5
5.0-10.9	60 ± 4.7	--	--	60 ± 5.0	59 ± 5.9	60 ± 4.9	60 ± 4.5
≥11.0	61 ± 3.9	61 ± 4.6	61 ± 4.8	61 ± 4.4	58 ± 4.0	61 ± 4.4	60 ± 3.2
Bark							
1.0- 4.9	50 ± 9.0	--	--	--	--	49 ± 10.3	59 ± 10.9
5.0-10.9	52 ± 8.0	--	--	50 ± 10.1	57 ± 7.3	51 ± 9.3	59 ± 5.1
≥11.0	55 ± 7.3	53 ± 9.5	55 ± 8.2	53 ± 9.1	60 ± 6.0	53 ± 9.0	59 ± 4.8
Wood and Bark							
1.0- 4.9	58 ± 4.8	--	--	--	--	58 ± 5.0	59 ± 6.3
5.0-10.9	59 ± 4.0	--	--	58 ± 4.4	59 ± 4.9	58 ± 4.3	59 ± 3.9
≥11.0	60 ± 3.8	60 ± 4.5	59 ± 4.4	60 ± 4.3	58 ± 3.4	60 ± 4.3	59 ± 2.9
RED MAPLE							
Wood							
1.0- 4.9	54 ± 5.5	--	--	--	--	54 ± 5.7	51 ± 4.6
5.0-10.9	55 ± 2.7	--	--	55 ± 3.1	54 ± 3.9	55 ± 3.0	55 ± 4.3
≥11.0	55 ± 3.6	55 ± 4.2	52 ± 3.2	54 ± 3.9	55 ± 4.1	54 ± 3.8	57 ± 3.3
Bark							
1.0- 4.9	57 ± 4.9	--	--	--	--	59 ± 3.8	54 ± 9.3
5.0-10.9	60 ± 3.4	--	--	61 ± 5.3	61 ± 3.0	61 ± 4.7	57 ± 4.2
≥11.0	64 ± 4.2	66 ± 4.7	67 ± 2.8	66 ± 3.8	67 ± 2.2	66 ± 3.7	60 ± 5.1
Wood and Bark							
1.0- 4.9	54 ± 4.8	--	--	--	--	55 ± 4.9	52 ± 4.6
5.0-10.9	55 ± 2.4	--	--	55 ± 3.1	55 ± 3.3	55 ± 2.9	55 ± 3.3
≥11.0	56 ± 3.4	56 ± 4.0	53 ± 3.1	56 ± 3.6	56 ± 3.8	56 ± 3.6	58 ± 3.3
SWEETGUM							
Wood							
1.0- 4.9	62 ± 4.6	--	--	--	--	62 ± 4.7	61 ± 6.0
5.0-10.9	62 ± 3.4	--	--	63 ± 3.8	62 ± 4.8	63 ± 3.6	62 ± 3.4
≥11.0	63 ± 2.3	63 ± 2.9	63 ± 2.9	63 ± 2.7	59 ± 3.8	63 ± 2.6	61 ± 2.7
Bark							
1.0- 4.9	45 ± 7.0	--	--	--	--	44 ± 7.8	59 ± 6.5
5.0-10.9	48 ± 6.0	--	--	44 ± 7.1	55 ± 6.1	46 ± 6.6	60 ± 3.4
≥11.0	52 ± 4.6	49 ± 6.4	51 ± 5.6	50 ± 5.9	58 ± 5.0	50 ± 5.8	59 ± 3.4

Continued

Table 5.--Average green weight per cubic foot of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Piedmont--Continued

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Pounds per cubic foot						
Wood and Bark							
1.0- 4.9	58 ± 3.2	--	--	--	--	57 ± 3.5	61 ± 5.4
5.0-10.9	60 ± 3.4	--	--	59 ± 3.8	60 ± 4.1	60 ± 3.6	61 ± 2.9
≥11.0	61 ± 2.3	62 ± 3.0	61 ± 2.7	62 ± 2.8	59 ± 3.3	62 ± 2.7	61 ± 2.5
SYCAMORE							
Wood							
1.0- 4.9	66 ± 5.7	--	--	--	--	67 ± 5.9	56 ± 7.1
5.0-10.9	64 ± 2.3	--	--	64 ± 2.3	65 ± 4.9	64 ± 2.6	63 ± 2.2
≥11.0	64 ± 4.2	66 ± 5.0	63 ± 3.9	65 ± 4.6	60 ± 2.8	65 ± 4.6	58 ± 3.2
Bark							
1.0- 4.9	63 ± 4.4	--	--	--	--	62 ± 5.3	75 ± 17.5
5.0-10.9	68 ± 2.9	--	--	69 ± 3.4	71 ± 3.3	69 ± 3.1	67 ± 5.0
≥11.0	67 ± 2.6	69 ± 2.4	69 ± 2.9	69 ± 2.5	68 ± 5.7	69 ± 2.5	66 ± 5.1
Wood and Bark							
1.0- 4.9	66 ± 5.4	--	--	--	--	66 ± 5.7	60 ± 3.3
5.0-10.9	64 ± 2.2	--	--	65 ± 2.2	65 ± 4.7	65 ± 2.8	63 ± 2.4
≥11.0	64 ± 4.1	66 ± 4.8	64 ± 3.8	65 ± 4.4	61 ± 2.7	65 ± 4.4	58 ± 3.1
YELLOW-POPLAR							
Wood							
1.0- 4.9	54 ± 5.3	--	--	--	--	54 ± 5.7	53 ± 2.2
5.0-10.9	56 ± 4.2	--	--	56 ± 4.7	53 ± 4.5	56 ± 4.5	56 ± 3.7
≥11.0	58 ± 2.4	58 ± 2.8	59 ± 4.0	58 ± 2.8	58 ± 3.8	58 ± 2.8	59 ± 1.5
Bark							
1.0- 4.9	56 ± 2.0	--	--	--	--	55 ± 2.8	57 ± 2.4
5.0-10.9	55 ± 6.0	--	--	55 ± 7.4	59 ± 5.7	55 ± 7.0	58 ± 4.6
≥11.0	52 ± 5.4	50 ± 7.0	53 ± 5.6	50 ± 6.7	58 ± 4.8	50 ± 6.6	56 ± 3.4
Wood and Bark							
1.0- 4.9	54 ± 3.9	--	--	--	--	54 ± 4.4	55 ± 1.9
5.0-10.9	55 ± 3.8	--	--	56 ± 4.4	54 ± 3.9	55 ± 4.2	56 ± 3.3
≥11.0	57 ± 2.3	57 ± 2.5	57 ± 3.8	57 ± 2.6	58 ± 3.2	57 ± 2.6	58 ± 1.5
HARD HARDWOODS							
Wood							
1.0- 4.9	64 ± 4.7	--	--	--	--	64 ± 4.9	65 ± 6.2
5.0-10.9	64 ± 4.6	--	--	64 ± 5.5	63 ± 5.1	64 ± 5.1	64 ± 3.7
≥11.0	66 ± 3.8	66 ± 4.6	67 ± 4.8	66 ± 4.4	66 ± 6.3	66 ± 4.4	66 ± 2.4

Continued

Table 5.--Average green weight per cubic foot of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Piedmont--Continued

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Pounds per cubic foot						
Bark							
1.0- 4.9	51 ± 10.6	--	--	--	--	52 ± 10.6	52 ± 12.9
5.0-10.9	57 ± 5.3	--	--	57 ± 6.7	59 ± 6.1	58 ± 6.6	59 ± 4.9
≥11.0	60 ± 3.7	61 ± 5.6	61 ± 5.2	61 ± 5.4	60 ± 3.9	61 ± 5.3	60 ± 4.2
Wood and Bark							
1.0- 4.9	61 ± 5.2	--	--	--	--	61 ± 4.8	61 ± 8.1
5.0-10.9	63 ± 4.1	--	--	63 ± 5.1	62 ± 4.2	63 ± 4.7	62 ± 3.0
≥11.0	65 ± 3.3	65 ± 4.1	66 ± 4.0	66 ± 4.0	64 ± 4.7	66 ± 3.9	64 ± 2.6
ELM							
Wood							
1.0- 4.9	63 ± 4.2	--	--	--	--	63 ± 4.3	60 ± 4.7
5.0-10.9	61 ± 1.8	--	--	62 ± 2.8	58 ± 3.3	61 ± 1.9	61 ± 3.0
Bark							
1.0- 4.9	46 ± 6.1	--	--	--	--	43 ± 5.2	53 ± 9.7
5.0-10.9	48 ± 4.9	--	--	49 ± 5.9	47 ± 4.7	48 ± 5.1	50 ± 7.2
Wood and Bark							
1.0- 4.9	58 ± 2.6	--	--	--	--	58 ± 3.5	59 ± 3.7
5.0-10.9	59 ± 1.7	--	--	61 ± 2.7	56 ± 3.1	60 ± 1.7	58 ± 3.6
HICKORY							
Wood							
1.0- 4.9	57 ± 1.7	--	--	--	--	57 ± 2.3	52 ± 8.3
5.0-10.9	58 ± 2.2	--	--	58 ± 2.5	54 ± 3.4	58 ± 2.2	60 ± 2.9
≥11.0	62 ± 4.2	62 ± 5.4	61 ± 2.3	62 ± 5.0	58 ± 3.8	62 ± 5.0	61 ± 2.2
Bark							
1.0- 4.9	61 ± 0.8	--	--	--	--	62 ± 0.8	62 ± 4.4
5.0-10.9	57 ± 1.8	--	--	59 ± 2.5	59 ± 1.1	59 ± 2.1	55 ± 2.3
≥11.0	59 ± 2.0	60 ± 2.0	61 ± 2.6	61 ± 2.0	60 ± 2.3	60 ± 1.9	56 ± 2.9
Wood and Bark							
1.0- 4.9	59 ± 1.3	--	--	--	--	59 ± 1.8	55 ± 4.6
5.0-10.9	58 ± 1.6	--	--	58 ± 2.2	55 ± 2.3	58 ± 1.9	58 ± 1.8
≥11.0	61 ± 3.3	62 ± 4.6	61 ± 1.9	62 ± 4.2	59 ± 3.2	62 ± 4.2	60 ± 2.0

Continued

Table 5.--Average green weight per cubic foot of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Piedmont--Continued

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Pounds per cubic foot						
CHESTNUT OAK							
Wood							
1.0- 4.9	60 ± 3.4	--	--	--	--	60 ± 3.5	60 ± 5.0
5.0-10.9	61 ± 2.8	--	--	61 ± 3.1	60 ± 6.7	61 ± 3.0	61 ± 3.3
≥11.0	59 ± 2.6	57 ± 3.3	62 ± 3.4	58 ± 3.4	57 ± 2.9	58 ± 3.3	62 ± 2.6
Bark							
1.0- 4.9	56 ± 2.8	--	--	--	--	56 ± 3.1	64 ± 12.0
5.0-10.9	53 ± 2.2	--	--	53 ± 2.0	54 ± 2.9	53 ± 2.1	56 ± 3.4
≥11.0	55 ± 0.5	56 ± 2.1	55 ± 3.1	55 ± 2.3	56 ± 0.1	55 ± 2.3	55 ± 2.5
Wood and Bark							
1.0- 4.9	59 ± 2.7	--	--	--	--	59 ± 2.9	61 ± 3.5
5.0-10.9	59 ± 2.4	--	--	59 ± 2.7	58 ± 4.5	59 ± 2.6	59 ± 3.0
≥11.0	58 ± 2.1	57 ± 3.1	60 ± 3.4	58 ± 3.1	57 ± 2.1	58 ± 3.0	59 ± 2.2
SCARLET OAK							
Wood							
5.0-10.9	68 ± 3.0	--	--	69 ± 3.8	63 ± 2.6	68 ± 3.7	65 ± 0.8
≥11.0	66 ± 2.8	66 ± 4.0	69 ± 3.5	67 ± 3.7	69 ± 4.8	67 ± 3.6	66 ± 0.8
Bark							
5.0-10.9	62 ± 2.2	--	--	65 ± 2.6	62 ± 3.1	64 ± 2.9	58 ± 0.5
≥11.0	63 ± 1.4	66 ± 3.0	66 ± 2.9	66 ± 2.6	63 ± 2.5	65 ± 2.5	60 ± 1.5
Wood and Bark							
5.0-10.9	67 ± 2.5	--	--	69 ± 3.5	63 ± 2.4	68 ± 3.4	63 ± 0.6
≥11.0	66 ± 2.3	66 ± 3.6	68 ± 3.0	66 ± 3.3	67 ± 3.8	66 ± 3.3	64 ± 0.6
SOUTHERN RED OAK							
Wood							
1.0- 4.9	61 ± 5.6	--	--	--	--	60 ± 6.3	65 ± 0.3
5.0-10.9	67 ± 2.5	--	--	67 ± 3.5	68 ± 4.1	67 ± 3.0	66 ± 2.1
≥11.0	65 ± 4.3	65 ± 5.2	67 ± 5.6	65 ± 5.1	67 ± 8.7	65 ± 5.1	65 ± 1.6
Bark							
1.0- 4.9	63 ± 0.2	--	--	--	--	65 ± 1.5	57 ± 3.9
5.0-10.9	62 ± 2.7	--	--	62 ± 4.1	64 ± 4.0	62 ± 4.0	61 ± 2.1
≥11.0	63 ± 2.6	64 ± 5.3	63 ± 2.4	64 ± 4.4	63 ± 2.5	64 ± 4.3	63 ± 1.2

Continued

Table 5.--Average green weight per cubic foot of wood, bark, and wood and bark combined, by tree component and size class, for hardwood species in the Piedmont--Continued

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Pounds per cubic foot						
Wood and Bark							
1.0- 4.9	61 ± 4.2	--	--	--	--	61 ± 4.9	62 ± 0.4
5.0-10.9	66 ± 2.1	--	--	66 ± 3.0	67 ± 2.5	66 ± 2.5	64 ± 1.1
≥11.0	65 ± 3.7	65 ± 4.8	66 ± 4.5	65 ± 4.6	66 ± 6.0	65 ± 4.6	64 ± 1.1
WHITE OAK							
Wood							
1.0- 4.9	62 ± 5.1	--	--	--	--	62 ± 5.1	64 ± 3.0
5.0-10.9	66 ± 2.9	--	--	67 ± 3.4	65 ± 3.7	67 ± 3.3	64 ± 2.6
≥11.0	68 ± 2.1	68 ± 2.8	69 ± 3.6	69 ± 2.7	67 ± 3.8	69 ± 2.7	67 ± 1.2
Bark							
1.0- 4.9	55 ± 3.7	--	--	--	--	55 ± 3.8	59 ± 8.6
5.0-10.9	55 ± 5.7	--	--	53 ± 6.5	55 ± 5.6	53 ± 6.3	60 ± 5.3
≥11.0	59 ± 3.9	58 ± 5.4	58 ± 5.6	58 ± 5.3	59 ± 4.3	58 ± 5.3	61 ± 5.5
Wood and Bark							
1.0- 4.9	61 ± 4.6	--	--	--	--	61 ± 4.8	62 ± 3.6
5.0-10.9	64 ± 3.0	--	--	65 ± 3.7	62 ± 3.2	64 ± 3.6	63 ± 1.1
≥11.0	67 ± 2.0	67 ± 2.6	68 ± 2.7	67 ± 2.5	64 ± 2.5	67 ± 2.5	66 ± 2.3
ALL SPECIES							
Wood							
1.0- 4.9	62 ± 5.8	--	--	--	--	62 ± 5.8	61 ± 7.6
5.0-10.9	62 ± 5.1	--	--	62 ± 5.6	61 ± 5.9	62 ± 5.4	61 ± 4.6
≥11.0	63 ± 4.7	63 ± 5.1	63 ± 5.8	63 ± 5.1	62 ± 6.4	63 ± 5.1	62 ± 4.2
Bark							
1.0- 4.9	50 ± 9.5	--	--	--	--	50 ± 10.4	57 ± 11.9
5.0-10.9	54 ± 7.5	--	--	53 ± 9.7	57 ± 6.9	54 ± 9.0	59 ± 5.0
≥11.0	57 ± 6.6	56 ± 8.9	58 ± 7.6	56 ± 8.5	60 ± 5.2	57 ± 8.4	59 ± 4.6
Wood and Bark							
1.0- 4.9	59 ± 5.1	--	--	--	--	59 ± 5.1	60 ± 6.9
5.0-10.9	60 ± 4.6	--	--	60 ± 5.3	60 ± 4.9	60 ± 5.0	60 ± 3.8
≥11.0	62 ± 4.5	62 ± 5.1	62 ± 5.4	62 ± 5.0	61 ± 5.0	62 ± 5.0	61 ± 3.8

Table 6.--Average green weight of wood and bark per cubic foot of wood, by tree component and size class, for hardwood species in the Piedmont

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Pounds per cubic foot						
SOFT HARDWOODS							
1.0- 4.9	74 ± 5.4	--	--	--	--	73 ± 5.5	85 ± 10.4
5.0-10.9	71 ± 5.1	--	--	69 ± 5.1	74 ± 6.9	69 ± 5.2	84 ± 8.2
≥11.0	70 ± 3.8	68 ± 4.0	71 ± 6.1	69 ± 4.0	77 ± 9.4	69 ± 4.0	80 ± 7.5
RED MAPLE							
1.0- 4.9	67 ± 4.1	--	--	--	--	66 ± 4.5	71 ± 6.3
5.0-10.9	64 ± 3.4	--	--	62 ± 3.8	66 ± 4.7	62 ± 3.8	73 ± 7.0
≥11.0	64 ± 4.6	62 ± 5.3	60 ± 4.4	61 ± 4.9	66 ± 5.6	62 ± 4.9	76 ± 5.0
SWEETGUM							
1.0- 4.9	76 ± 3.8	--	--	--	--	75 ± 4.0	90 ± 8.5
5.0-10.9	73 ± 4.0	--	--	71 ± 4.1	77 ± 6.0	72 ± 4.1	89 ± 5.4
≥11.0	72 ± 2.7	70 ± 3.1	74 ± 4.4	70 ± 2.9	80 ± 9.4	70 ± 2.9	83 ± 4.7
SYCAMORE							
1.0- 4.9	71 ± 6.3	--	--	--	--	71 ± 6.2	80 ± 5.1
5.0-10.9	69 ± 1.9	--	--	68 ± 2.0	70 ± 4.7	68 ± 2.2	75 ± 3.9
≥11.0	67 ± 4.4	68 ± 5.0	66 ± 4.4	68 ± 4.6	66 ± 2.7	68 ± 4.6	65 ± 4.8
YELLOW-POPLAR							
1.0- 4.9	75 ± 7.2	--	--	--	--	72 ± 5.5	91 ± 9.0
5.0-10.9	68 ± 4.6	--	--	66 ± 4.9	71 ± 6.2	67 ± 4.7	82 ± 8.3
≥11.0	70 ± 2.9	68 ± 3.1	73 ± 4.9	69 ± 3.1	80 ± 6.1	69 ± 3.1	83 ± 4.1
HARD HARDWOODS							
1.0- 4.9	81 ± 4.7	--	--	--	--	79 ± 5.1	88 ± 6.9
5.0-10.9	79 ± 6.1	--	--	76 ± 6.7	81 ± 6.4	77 ± 6.3	90 ± 7.7
≥11.0	79 ± 3.5	75 ± 4.0	80 ± 5.0	76 ± 4.0	89 ± 8.3	76 ± 4.0	87 ± 3.2
ELM							
1.0- 4.9	79 ± 4.7	--	--	--	--	77 ± 5.3	85 ± 9.5
5.0-10.9	70 ± 4.4	--	--	68 ± 4.2	73 ± 3.9	68 ± 4.1	79 ± 6.8
HICKORY							
1.0- 4.9	83 ± 0.6	--	--	--	--	83 ± 1.4	83 ± 9.9
5.0-10.9	81 ± 4.9	--	--	76 ± 2.7	79 ± 2.9	77 ± 2.7	96 ± 6.9
≥11.0	78 ± 3.7	75 ± 4.2	76 ± 1.8	75 ± 3.7	80 ± 2.3	75 ± 3.6	88 ± 4.6
CHESTNUT OAK							
1.0- 4.9	82 ± 1.9	--	--	--	--	80 ± 2.0	98 ± 4.4
5.0-10.9	78 ± 2.8	--	--	76 ± 3.2	80 ± 8.6	76 ± 3.1	97 ± 7.6
≥11.0	76 ± 1.0	70 ± 2.1	79 ± 1.5	72 ± 2.1	80 ± 5.8	72 ± 2.1	90 ± 4.7

Continued

Table 6.--Average green weight of wood and bark per cubic foot of wood, by tree component and size class, for hardwood species in the Piedmont--Continued

Tree size class (inches)	Average and standard deviation						
	Total tree	Stem					Branches
		Butt to 9-inch top	9-inch to 4-inch top	Butt to 4-inch top	4-inch to tip	Butt to tip	
	Pounds per cubic foot						
SCARLET OAK							
5.0-10.9	81 ± 3.1	--	--	80 ± 3.4	78 ± 3.1	79 ± 3.3	90 ± 4.3
≥11.0	79 ± 3.2	76 ± 4.1	80 ± 3.1	76 ± 3.8	88 ± 4.5	77 ± 3.7	85 ± 1.7
SOUTHERN RED OAK							
1.0- 4.9	80 ± 0.6	--	--	--	--	78 ± 0.6	93 ± 3.6
5.0-10.9	84 ± 2.9	--	--	82 ± 3.7	88 ± 8.1	83 ± 3.7	93 ± 7.7
≥11.0	80 ± 4.5	76 ± 5.2	83 ± 6.5	78 ± 5.3	92 ± 12.3	78 ± 5.4	87 ± 2.3
WHITE OAK							
1.0- 4.9	79 ± 1.8	--	--	--	--	78 ± 1.4	102 ± 4.3
5.0-10.9	80 ± 3.8	--	--	77 ± 3.8	83 ± 5.3	78 ± 3.8	89 ± 4.3
≥11.0	79 ± 2.4	76 ± 2.8	80 ± 4.0	76 ± 2.7	91 ± 4.9	76 ± 2.7	89 ± 2.3
ALL SPECIES							
1.0- 4.9	76 ± 6.0	--	--	--	--	75 ± 6.1	86 ± 9.5
5.0-10.9	74 ± 6.7	--	--	72 ± 6.8	77 ± 7.5	72 ± 6.7	87 ± 8.5
≥11.0	74 ± 5.6	71 ± 5.3	75 ± 7.0	72 ± 5.4	82 ± 10.6	72 ± 5.4	83 ± 7.0

Table 7.--Regression equations for estimating green and dry weight of above-stump total-tree wood, bark, and foliage, wood and bark combined, and wood alone for hardwood species in the Piedmont, with d.b.h. as the independent variable

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
TOTAL-TREE WOOD, BARK, AND FOLIAGE								
Soft Hardwoods	Green	3.73782	1.24651	3.72881	1.24702	0.99	0.0743	435
	Dry	1.84450	1.24271	1.79335	1.24857	0.99	0.0859	435
Red maple	Green	5.36391	1.15934	6.98338	1.10433	0.99	0.0617	32
	Dry	2.79850	1.17348	2.67230	1.18311	0.99	0.0616	32
Sweetgum	Green	3.52244	1.25422	2.73784	1.30676	0.99	0.0660	236
	Dry	1.59389	1.26123	1.11956	1.33488	0.99	0.0691	236
Sycamore	Green	3.45877	1.29420	5.69330	1.19029	0.98	0.0914	29
	Dry	1.57573	1.29005	2.51502	1.19256	0.98	0.0903	29
Yellow-poplar	Green	5.34413	1.16528	3.86208	1.23301	0.99	0.0563	78
	Dry	2.26626	1.19993	2.07889	1.21792	0.99	0.0569	78
Hard Hardwoods	Green	4.37384	1.24797	3.77719	1.27855	0.99	0.0831	338
	Dry	2.33125	1.27239	2.65719	1.24510	0.99	0.0832	338
Elm species	Green	3.55150	1.29029	-	-	0.99	0.1089	16
	Dry	2.17565	1.24810	-	-	0.98	0.1497	16
Hickory species	Green	3.91388	1.25991	2.07847	1.39188	0.99	0.0875	22
	Dry	2.28678	1.26943	1.45618	1.36354	0.99	0.0817	22
Chestnut oak	Green	3.58393	1.26451	-	-	0.98	0.1001	37
	Dry	2.07216	1.27407	-	-	0.99	0.0952	37
Scarlet oak	Green	7.67883	1.12892	5.18502	1.21080	0.98	0.0584	32
	Dry	4.62402	1.11826	3.25755	1.19130	0.97	0.0619	32
South. red oak	Green	4.16110	1.24480	3.59805	1.27512	0.99	0.0619	48
	Dry	2.30252	1.25795	2.23731	1.26394	0.99	0.0658	48

Continued

Table 7.--Regression equations for estimating green and dry weight of above-stump total-tree wood, bark, and foliage, wood and bark combined, and wood alone for hardwood species in the Piedmont, with d.b.h. as the independent variable--Continued

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
White oak	Green	3.77906	1.28582	4.12381	1.26762	0.99	0.0628	110
	Dry	2.17051	1.29463	2.75327	1.24504	0.99	0.0639	110
All Species	Green	4.02178	1.24683	3.77086	1.26026	0.99	0.0858	773
	Dry	2.07266	1.25582	2.17269	1.24599	0.98	0.1127	773
				TOTAL-TREE WOOD AND BARK				
Soft Hardwoods	Green	3.45441	1.25662	3.56126	1.25027	0.99	0.0735	435
	Dry	1.76000	1.24794	1.70240	1.25488	0.99	0.0858	435
Red maple	Green	4.67742	1.18264	8.54253	1.05705	0.99	0.0644	32
	Dry	2.57712	1.18599	3.05746	1.15035	0.99	0.0644	32
Sweetgum	Green	3.27747	1.26281	2.52632	1.31709	0.99	0.0656	236
	Dry	1.53102	1.26483	1.02343	1.34881	0.99	0.0700	236
Sycamore	Green	3.45375	1.28604	5.53455	1.18772	0.98	0.0896	29
	Dry	1.59196	1.28224	2.49193	1.18881	0.98	0.0892	29
Yellow-poplar	Green	4.85459	1.17925	3.70384	1.23567	0.99	0.0565	78
	Dry	2.15905	1.20611	1.99365	1.22273	0.99	0.0577	78
Hard Hardwoods	Green	3.94158	1.26290	3.78872	1.27115	0.99	0.0816	338
	Dry	2.19726	1.27902	2.63110	1.24145	0.99	0.0824	338
Elm species	Green	3.24468	1.30218	-	-	0.99	0.1080	16
	Dry	2.04282	1.25462	-	-	0.98	0.1487	16
Hickory species	Green	3.54512	1.27159	1.96464	1.39467	0.99	0.0849	22
	Dry	2.12752	1.27670	1.40563	1.36312	0.99	0.0809	22
Chestnut oak	Green	3.36285	1.26827	-	-	0.99	0.0953	37
	Dry	1.97742	1.27701	-	-	0.99	0.0919	37

Continued

Table 7.--Regression equations for estimating green and dry weight of above-stump total-tree wood, bark, and foliage, wood and bark combined, and wood alone for hardwood species in the Piedmont, with d.b.h. as the independent variable--Continued

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
Scarlet oak	Green	6.97167	1.14034	5.08292	1.20623	0.98	0.0513	32
	Dry	4.29269	1.12622	3.29755	1.18121	0.98	0.0557	32
South. red oak	Green	3.79154	1.25816	3.65002	1.26610	0.99	0.0650	48
	Dry	2.16190	1.26622	2.24331	1.25852	0.99	0.0674	48
White oak	Green	3.59943	1.28743	3.83734	1.27409	0.99	0.0624	110
	Dry	2.10740	1.29427	2.61564	1.24922	0.99	0.0636	110
All Species	Green	3.67241	1.25923	3.68006	1.25879	0.99	0.0840	773
	Dry	1.96533	1.26171	2.09786	1.24810	0.98	0.1113	773
				TOTAL-TREE WOOD				
Soft Hardwoods	Green	2.69151	1.27896	3.09999	1.24950	0.99	0.0783	435
	Dry	1.40258	1.26551	1.50675	1.25057	0.99	0.0898	435
Red maple	Green	3.59496	1.21112	10.15858	0.99452	0.99	0.0685	32
	Dry	2.00850	1.21442	3.30769	1.11040	0.99	0.0683	32
Sweetgum	Green	2.53317	1.28762	2.11801	1.32495	0.99	0.0690	236
	Dry	1.21586	1.28167	0.86858	1.35180	0.99	0.0737	236
Sycamore	Green	3.18226	1.29035	4.93410	1.19890	0.98	0.0917	29
	Dry	1.46669	1.28586	2.28758	1.19318	0.98	0.0914	29
Yellow-poplar	Green	3.21823	1.22820	3.20054	1.22935	0.99	0.0567	78
	Dry	1.49256	1.25062	1.83348	1.20772	0.99	0.0597	78
Hard Hardwoods	Green	3.07161	1.27581	2.83843	1.29227	0.99	0.0903	338
	Dry	1.79309	1.28120	2.00363	1.25805	0.99	0.0904	338
Elm species	Green	2.47940	1.33256	-	-	0.99	0.1060	16
	Dry	1.61626	1.27640	-	-	0.98	0.1500	16

Continued

Table 7.--Regression equations for estimating green and dry weight of above-stump total-tree wood, bark, and foliage, wood and bark combined, and wood alone for hardwood species in the Piedmont, with d.b.h. as the independent variable--Continued

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
Hickory species	Green	2.39541	1.29158	0.95325	1.48372	0.99	0.0801	22
	Dry	1.47448	1.30237	0.80484	1.42846	0.99	0.0812	22
Chestnut oak	Green	2.38060	1.29596	-	-	0.98	0.1038	37
	Dry	1.47803	1.29164	-	-	0.98	0.1052	37
Scarlet oak	Green	5.64242	1.14657	3.91334	1.22288	0.98	0.0514	32
	Dry	3.58160	1.12404	2.65478	1.18648	0.98	0.0569	32
South. red oak	Green	2.69921	1.28577	2.75307	1.28165	0.99	0.0686	48
	Dry	1.60609	1.28082	1.75184	1.26271	0.98	0.0701	48
White oak	Green	2.61921	1.32022	3.09258	1.28557	0.99	0.0646	110
	Dry	1.62310	1.31548	2.16091	1.25581	0.99	0.0655	110
All Species	Green	2.86050	1.27724	2.99656	1.26756	0.99	0.0877	773
	Dry	1.58099	1.27211	1.72982	1.25335	0.98	0.1114	773

[1]Trees < 11.0 inches d.b.h.

$Y = a'(D^2)^b$

[2]Trees ≥ 11.0 inches d.b.h.

$Y = a''(D^2)^b$

Where: Y = component weight in pounds
D = tree d.b.h. in inches
a', a", b = regression coefficients

[3]$\log_{10}$ form

Table 8.--Regression equations for estimating green and dry weight of total-stem wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. as the independent variable

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL-STEM WOOD AND BARK				
Soft Hardwoods	Green	2.88400	1.26739	4.62115	1.16908	0.99	0.0760	435
	Dry	1.46664	1.25919	2.23750	1.17111	0.99	0.0848	435
Red maple	Green	3.43213	1.21974	36.05579	0.72933	0.99	0.0830	32
	Dry	1.89307	1.22502	11.29115	0.85265	0.99	0.0856	32
Sweetgum	Green	2.84702	1.26986	3.92363	1.20252	0.99	0.0666	236
	Dry	1.31287	1.27472	1.68638	1.22252	0.99	0.0720	236
Sycamore	Green	3.85492	1.21745	3.47106	1.23933	0.98	0.0889	29
	Dry	1.80787	1.20679	1.52656	1.24206	0.98	0.0887	29
Yellow-poplar	Green	4.16189	1.18760	4.74211	1.16039	0.98	0.0602	78
	Dry	1.83937	1.21873	2.61846	1.14509	0.98	0.0594	78
Hard Hardwoods	Green	3.26545	1.25704	7.84482	1.07428	0.99	0.0787	338
	Dry	1.84449	1.27009	6.03182	1.02303	0.99	0.0816	338
Elm species	Green	2.50952	1.28580	-	-	0.99	0.1114	16
	Dry	1.63763	1.21880	-	-	0.98	0.1575	16
Hickory species	Green	3.21191	1.22618	2.06379	1.31841	0.99	0.0683	22
	Dry	1.97528	1.23186	1.72985	1.25953	0.99	0.0708	22
Chestnut oak	Green	2.91108	1.25815	-	-	0.99	0.0918	37
	Dry	1.74635	1.26402	-	-	0.99	0.0904	37
Scarlet oak	Green	7.30927	1.06838	7.07711	1.07511	0.99	0.0430	32
	Dry	4.55975	1.04716	4.96382	1.02946	0.99	0.0402	32
South. red oak	Green	3.42543	1.24413	8.29811	1.05964	0.98	0.0769	48
	Dry	1.96985	1.24888	5.74409	1.02572	0.98	0.0789	48
White oak	Green	3.94053	1.20929	4.92392	1.16284	0.99	0.0629	110
	Dry	2.33238	1.21371	3.62486	1.12177	0.99	0.0652	110

Continued

Table 8.--Regression equations for estimating green and dry weight of total-stem wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. as the independent variable--Continued

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
All Species	Green	3.05596	1.26193	5.72003	1.13122	0.99	0.0789	773
	Dry	1.63740	1.26316	3.40599	1.11043	0.98	0.0992	773
				TOTAL-STEM WOOD				
Soft Hardwoods	Green	2.29553	1.28964	3.93834	1.17708	0.99	0.0803	435
	Dry	1.19593	1.27529	1.93202	1.17527	0.99	0.0882	435
Red maple	Green	2.71814	1.24661	37.16936	0.70123	0.99	0.0847	32
	Dry	1.54154	1.24764	11.01055	0.83768	0.99	0.0859	32
Sweetgum	Green	2.23375	1.29553	3.17921	1.22194	0.99	0.0699	236
	Dry	1.06049	1.29157	1.38257	1.23627	0.99	0.0749	236
Sycamore	Green	3.57651	1.22324	3.15518	1.24938	0.98	0.0900	29
	Dry	1.67801	1.21177	1.42020	1.24655	0.98	0.0897	29
Yellow-poplar	Green	2.92832	1.22727	3.88793	1.16817	0.98	0.0598	78
	Dry	1.34294	1.25372	2.28931	1.14250	0.98	0.0602	78
Hard Hardwoods	Green	2.55430	1.27648	5.93585	1.10065	0.99	0.0867	338
	Dry	1.50661	1.27832	4.62594	1.04441	0.99	0.0884	338
Elm species	Green	1.99983	1.31513	-	-	0.99	0.1116	16
	Dry	1.35944	1.23738	-	-	0.98	0.1588	16
Hickory species	Green	2.16113	1.25706	0.99368	1.41907	0.99	0.0698	22
	Dry	1.34563	1.26652	0.95566	1.33788	0.99	0.0740	22
Chestnut oak	Green	2.10341	1.28826	-	-	0.98	0.1018	37
	Dry	1.31709	1.28164	-	-	0.98	0.1036	37
Scarlet oak	Green	5.86508	1.08429	5.87333	1.08399	0.99	0.0440	32
	Dry	3.77556	1.05401	4.34532	1.05401	0.99	0.0407	32
South. red oak	Green	2.47712	1.27276	6.05373	1.08643	0.98	0.0785	48
	Dry	1.48494	1.26384	4.35351	1.03956	0.98	0.0797	48

Continued

Table 8.--Regression equations for estimating green and dry weight of total-stem wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. as the independent variable--Continued

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
White oak	Green	2.83704	1.25375	4.14649	1.17462	0.99	0.0671	110
	Dry	1.77828	1.24515	3.07673	1.13084	0.99	0.0687	110
All Species	Green	2.41288	1.28299	4.63505	1.14686	0.99	0.0839	773
	Dry	1.33502	1.27564	2.78765	1.12212	0.98	0.1005	773

[1]Trees < 11.0 inches d.b.h.

$$Y = a'(D^2)^b$$

[2]Trees $\geq$ 11.0 inches d.b.h.

$$Y = a''(D^2)^b$$

Where: Y = component weight in pounds
D = tree d.b.h. in inches
a', a", b = regression coefficients

[3]$\log_{10}$ form

Table 9.--Regression equations for estimating cubic-foot volume of above-stump total-tree wood and bark combined and wood alone for hardwood species in the Piedmont using d.b.h. as the independent variable

Species or species group	Volume wood & bark or wood only	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL TREE				
Soft Hardwoods	Wd&Bk	0.06133	1.24731	0.06577	1.23275	0.99	0.0761	435
	Wood	0.04528	1.27576	0.05456	1.23689	0.99	0.0796	435
Red maple	Wd&Bk	0.08902	1.16798	0.15839	1.04783	0.99	0.0545	32
	Wood	0.06925	1.19637	0.18274	0.99405	0.99	0.0542	32
Sweetgum	Wd&Bk	0.05777	1.25093	0.05074	1.27799	0.99	0.0644	236
	Wood	0.04174	1.28099	0.03627	1.31030	0.99	0.0678	236
Sycamore	Wd&Bk	0.04866	1.31311	0.11283	1.13773	0.98	0.0868	29
	Wood	0.04437	1.32068	0.10279	1.14566	0.98	0.0887	29
Yellow-poplar	Wd&Bk	0.09562	1.15688	0.06793	1.22818	0.98	0.0590	78
	Wood	0.06617	1.19490	0.06550	1.19703	0.99	0.0551	78
Hard Hardwoods	Wd&Bk	0.06449	1.25435	0.07088	1.23465	0.99	0.0784	338
	Wood	0.04773	1.27429	0.05220	1.25584	0.99	0.0830	338
Elm species	Wd&Bk	0.05579	1.30112	-	-	0.99	0.1107	16
	Wood	0.03880	1.34482	-	-	0.99	0.1045	16
Hickory species	Wd&Bk	0.06089	1.27111	0.05047	1.31025	0.99	0.0802	22
	Wood	0.04183	1.28582	0.02587	1.38625	0.99	0.0695	22
Chestnut oak	Wd&Bk	0.05722	1.26048	-	-	0.99	0.0842	37
	Wood	0.04025	1.28301	-	-	0.99	0.0921	37
Scarlet oak	Wd&Bk	0.10028	1.15114	0.07664	1.20721	0.99	0.0475	32
	Wood	0.07922	1.16019	0.05809	1.22490	0.99	0.0461	32
South. red oak	Wd&Bk	0.06334	1.23536	0.04623	1.30129	0.99	0.0637	48
	Wood	0.04503	1.25694	0.03162	1.33367	0.99	0.0649	48

Continued

Table 9.--Regression equations for estimating cubic-foot volume of above-stump total-tree wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. as the independent variable--Continued

Species or species group	Volume wood & bark or wood only	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
White oak	Wd&Bk	0.06322	1.25707	0.06375	1.25535	0.99	0.0609	110
	Wood	0.04497	1.28857	0.04809	1.27460	0.99	0.0606	110
All Species	Wd&Bk	0.06272	1.25045	0.06812	1.23323	0.99	0.0787	773
	Wood	0.04639	1.27498	0.05360	1.24488	0.99	0.0817	773

[1]Trees < 11.0 inches d.b.h.

$$Y = a'(D^2)^b$$

[2]Trees ≥ 11.0 inches d.b.h.

$$Y = a''(D^2)^b$$

Where: Y = component volume in cubic feet
D = tree d.b.h. in inches
a', a", b = regression coefficients

[3]$\log_{10}$ form

Table 10.--Regression equations for estimating cubic-foot volume of total-stem wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. as the independent variable

Species or species group	Volume wood & bark or wood only	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL STEM				
Soft Hardwoods	Wd&Bk	0.05122	1.25830	0.09012	1.14049	0.99	0.0758	435
	Wood	0.03847	1.28688	0.07226	1.15544	0.99	0.0780	435
Red maple	Wd&Bk	0.06336	1.21217	0.66306	0.72257	0.99	0.0684	32
	Wood	0.05114	1.23716	0.65278	0.70613	0.99	0.0673	32
Sweetgum	Wd&Bk	0.04986	1.26029	0.08756	1.14285	0.99	0.0662	236
	Wood	0.03652	1.29093	0.05882	1.19153	0.99	0.0682	236
Sycamore	Wd&Bk	0.05459	1.24104	0.07330	1.17957	0.98	0.0852	29
	Wood	0.05013	1.24991	0.06810	1.18604	0.98	0.0858	29
Yellow-poplar	Wd&Bk	0.08183	1.16608	0.08798	1.50960	0.98	0.0648	78
	Wood	0.06001	1.19469	0.07990	1.13499	0.98	0.0598	78
Hard Hardwoods	Wd&Bk	0.05376	1.24627	0.14796	1.03514	0.99	0.0778	338
	Wood	0.04021	1.27213	0.10886	1.06448	0.99	0.0823	338
Elm species	Wd&Bk	0.04369	1.27843	-	-	0.99	0.1099	16
	Wood	0.03127	1.32648	-	-	0.99	0.1081	16
Hickory species	Wd&Bk	0.05484	1.22724	0.06012	1.20805	0.99	0.0646	22
	Wood	0.03771	1.25407	0.03115	1.29395	0.99	0.0617	22
Chestnut oak	Wd&Bk	0.04993	1.24922	-	-	0.99	0.0813	37
	Wood	0.03565	1.27559	-	-	0.99	0.0894	37
Scarlet oak	Wd&Bk	0.10646	1.07358	0.10101	1.08455	0.98	0.0488	32
	Wood	0.08287	1.09534	0.08420	1.09203	0.98	0.0488	32
South. red oak	Wd&Bk	0.05764	1.21902	0.10204	1.09994	0.98	0.0741	48
	Wood	0.04290	1.23743	0.06547	1.14927	0.98	0.0720	48

Continued

Table 10.--Regression equations for estimating cubic-foot volume of total-stem wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. as the independent variable

Species or species group	Volume wood & bark or wood only	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
White oak	Wd&Bk	0.07001	1.17560	0.08321	1.13957	0.99	0.0620	110
	Wood	0.04919	1.21908	0.06392	1.16447	0.99	0.0637	110
All Species	Wd&Bk	0.05245	1.25226	0.10979	1.09820	0.99	0.0771	773
	Wood	0.03933	1.27963	0.08489	1.11920	0.99	0.0804	773

[1]Trees < 11.0 inches d.b.h.

$$Y = a'(D^2)^b$$

[2]Trees $\geq$ 11.0 inches d.b.h.

$$Y = a''(D^2)^b$$

Where: Y = component volume in cubic feet
D = tree d.b.h. in inches
a', a", b = regression coefficients

[3]$\log_{10}$ form

Table 11.--Regression equations for estimating green and dry weight of above-stump total-tree wood, bark, and foliage, wood and bark combined, and wood alone for hardwood species in the Piedmont, with d.b.h. and total height as independent variables

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
		TOTAL-TREE WOOD, BARK, AND FOLIAGE							
Soft Hardwoods	Green	0.26936	0.93662	0.11762	1.10939	0.93662	0.99	0.0624	435
	Dry	0.13490	0.93309	0.05689	1.11312	0.93309	0.99	0.0793	435
Red maple	Green	0.39183	0.89196	0.10150	1.17362	0.89196	0.99	0.0571	32
	Dry	0.19766	0.90302	0.03697	1.25258	0.90302	0.99	0.0553	32
Sweetgum	Green	0.25462	0.93830	0.07753	1.18624	0.93830	0.99	0.0572	236
	Dry	0.11357	0.94351	0.03107	1.21330	0.94351	0.99	0.0609	236
Sycamore	Green	0.13562	1.03417	0.35092	0.83594	1.03417	0.99	0.0623	29
	Dry	0.06195	1.03171	0.15708	0.83771	1.03171	0.99	0.0580	29
Yellow-poplar	Green	0.30167	0.92608	0.15034	1.07131	0.92608	0.99	0.0421	78
	Dry	0.12309	0.94820	0.07267	1.05809	0.94820	0.99	0.0509	78
Hard Hardwoods	Green	0.34177	0.93392	0.07063	1.26268	0.93392	0.99	0.0770	338
	Dry	0.17320	0.95225	0.04598	1.22878	0.95225	0.99	0.0765	338
Elm species	Green	0.28983	0.94981	-	-	-	0.99	0.0877	16
	Dry	0.19128	0.91936	-	-	-	0.99	0.1304	16
Hickory species	Green	0.32136	0.94256	0.07871	1.23589	0.94256	0.99	0.0784	22
	Dry	0.18315	0.95030	0.05406	1.20474	0.95030	0.99	0.0677	22
Chestnut oak	Green	0.20469	0.98361	-	-	-	0.99	0.0679	37
	Dry	0.11665	0.99033	-	-	-	0.99	0.0668	37
Scarlet oak	Green	0.34542	0.94737	0.10278	1.20014	0.94737	0.97	0.0696	32
	Dry	0.21669	0.93708	0.06694	1.18201	0.93708	0.95	0.0732	32
South. red oak	Green	0.30456	0.94228	0.10284	1.16866	0.94228	0.99	0.0457	48
	Dry	0.16220	0.95348	0.06195	1.15418	0.95348	0.99	0.0476	48

Continued

Table 11.--Regression equations for estimating green and dry weight of above-stump total-tree wood, bark, and foliage, wood and bark combined, and wood alone for hardwood species in the Piedmont, with d.b.h. and total height as independent variables--Continued

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
White oak	Green	0.24019	0.98258	0.10382	1.15748	0.98258	0.99	0.0526	110
	Dry	0.13493	0.98969	0.06771	1.13346	0.98969	0.99	0.0525	110
All Species	Green	0.30645	0.93307	0.09434	1.17874	0.93307	0.99	0.0864	773
	Dry	0.15769	0.93800	0.05216	1.16867	0.93800	0.98	0.1197	773
				TOTAL-TREE WOOD AND BARK					
Soft Hardwoods	Green	0.24306	0.94449	0.10946	1.11083	0.94449	0.99	0.0595	435
	Dry	0.12693	0.93728	0.05332	1.11815	0.93728	0.99	0.0779	435
Red maple	Green	0.32214	0.91052	0.11496	1.12538	0.91052	0.99	0.0541	32
	Dry	0.17603	0.91317	0.04068	1.21861	0.91317	0.99	0.0534	32
Sweetgum	Green	0.23205	0.94503	0.06999	1.19494	0.94503	0.99	0.0548	236
	Dry	0.10800	0.94648	0.02818	1.22662	0.94648	0.99	0.0603	236
Sycamore	Green	0.13774	1.02804	0.34788	0.83485	1.02804	0.99	0.0587	29
	Dry	0.06368	1.02573	0.15849	0.83560	1.02573	0.99	0.0558	29
Yellow-poplar	Green	0.26330	0.93782	0.13885	1.07125	0.93782	0.99	0.0409	78
	Dry	0.11509	0.95352	0.06855	1.06155	0.95352	0.99	0.0511	78
Hard Hardwoods	Green	0.29779	0.94543	0.06774	1.25419	0.94543	0.99	0.0731	338
	Dry	0.16065	0.95747	0.04467	1.22435	0.95747	0.99	0.0740	338
Elm species	Green	0.25810	0.95874	-	-	-	0.99	0.0833	16
	Dry	0.17690	0.92435	-	-	-	0.99	0.1272	16
Hickory species	Green	0.28410	0.95141	0.07224	1.23694	0.95141	0.99	0.0747	22
	Dry	0.16922	0.95583	0.05168	1.20316	0.95583	0.99	0.0659	22
Chestnut oak	Green	0.19171	0.98587	-	-	-	0.99	0.0667	37
	Dry	0.11122	0.99205	-	-	-	0.99	0.0673	37

Continued

Table 11.--Regression equations for estimating green and dry weight of above-stump total-tree wood, bark, and foliage, wood and bark combined, and wood alone for hardwood species in the Piedmont, with d.b.h. and total height as independent variables--Continued

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
Scarlet oak	Green	0.29820	0.95918	0.09697	1.19341	0.95918	0.97	0.0623	32
	Dry	0.19339	0.94580	0.06601	1.16994	0.94580	0.97	0.0668	32
South. red oak	Green	0.26488	0.95457	0.10144	1.15471	0.95457	0.99	0.0442	48
	Dry	0.14786	0.96117	0.06106	1.14557	0.96117	0.99	0.0462	48
White oak	Green	0.22734	0.98415	0.09632	1.16321	0.98415	0.99	0.0510	110
	Dry	0.13069	0.98979	0.06451	1.13699	0.98979	0.99	0.0509	110
All Species	Green	0.27176	0.94274	0.08903	1.17543	0.94274	0.99	0.0827	773
	Dry	0.14724	0.94275	0.04964	1.16948	0.94275	0.98	0.1171	773
				TOTAL-TREE WOOD					
Soft Hardwoods	Green	0.17980	0.96177	0.08990	1.10631	0.96177	0.99	0.0618	435
	Dry	0.09703	0.95097	0.04511	1.11065	0.95097	0.99	0.0796	435
Red maple	Green	0.23096	0.93295	0.12402	1.06261	0.93295	0.99	0.0536	32
	Dry	0.12808	0.93549	0.03989	1.17871	0.93549	0.99	0.0534	32
Sweetgum	Green	0.16922	0.96425	0.05500	1.19861	0.96425	0.99	0.0541	236
	Dry	0.08213	0.95995	0.02297	1.22561	0.95995	0.99	0.0592	236
Sycamore	Green	0.12507	1.03190	0.30789	0.84406	1.03190	0.99	0.0603	29
	Dry	0.05797	1.02895	0.14459	0.83837	1.02895	0.99	0.0578	29
Yellow-poplar	Green	0.15548	0.97611	0.10454	1.05888	0.97611	0.99	0.0409	78
	Dry	0.07235	0.98718	0.05550	1.04247	0.98718	0.99	0.0551	78
Hard Hardwoods	Green	0.22486	0.95562	0.04892	1.27369	0.95562	0.99	0.0796	338
	Dry	0.12984	0.95964	0.03394	1.23943	0.95964	0.99	0.0798	338
Elm species	Green	0.18592	0.98109	-	-	-	0.99	0.0798	16
	Dry	0.13407	0.94042	-	-	-	0.99	0.1277	16

Continued

Table 11.--Regression equations for estimating green and dry weight of above-stump total-tree wood, bark, and foliage, wood and bark combined, and wood alone for hardwood species in the Piedmont, with d.b.h. and total height as independent variables--Continued

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
Hickory species	Green	0.18370	0.96680	0.03339	1.32235	0.96680	0.99	0.0658	22
	Dry	0.11002	0.97549	0.02756	1.26413	0.97549	0.99	0.0624	22
Chestnut oak	Green	0.12608	1.00846	-	-	-	0.99	0.0678	37
	Dry	0.07904	1.00511	-	-	-	0.99	0.0702	37
Scarlet oak	Green	0.23667	0.96469	0.07307	1.20974	0.96469	0.98	0.0623	32
	Dry	0.16244	0.94389	0.05354	1.17531	0.94389	0.97	0.0679	32
South. red oak	Green	0.17607	0.97670	0.07110	0.16576	0.97670	0.99	0.0454	48
	Dry	0.10609	0.97270	0.04584	1.14767	0.97270	0.99	0.0484	48
White oak	Green	0.15297	1.01011	0.07099	1.17020	1.01011	0.99	0.0498	110
	Dry	0.09539	1.00695	0.05039	1.14000	1.00695	0.99	0.0494	110
All Species	Green	0.20242	0.95702	0.06917	1.18091	0.95702	0.99	0.0825	773
	Dry	0.11508	0.95131	0.03994	1.17198	0.95131	0.98	0.1144	773

[1]Trees < 11.0 inches d.b.h.

$Y = a'(D^2Th)^b$

[2]Trees $\geq$ 11.0 inches d.b.h.

$Y = a''(D^2)^b (Th)^c$

Where: Y = component weight in pounds
D = tree d.b.h. in inches
Th = tree total height in feet
a', a", b, c = regression coefficients

[3]$\log_{10}$ form

Table 12.--Regression equations for estimating green and dry weight of total-stem wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. and total height as independent variables

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL-STEM WOOD AND BARK					
Soft Hardwoods	Green	0.19535	0.95420	0.13963	1.02422	0.95420	0.99	0.0509	435
	Dry	0.10185	0.94724	0.06873	1.02926	0.94724	0.99	0.0684	435
Red maple	Green	0.21176	0.94169	0.43801	0.79014	0.94169	0.99	0.0533	32
	Dry	0.11548	0.94569	0.13444	0.91400	0.94569	0.99	0.0576	32
Sweetgum	Green	0.19644	0.95126	0.10744	1.07709	0.95126	0.99	0.0493	236
	Dry	0.08995	0.95479	0.04550	1.09690	0.95479	0.99	0.0569	236
Sycamore	Green	0.17930	0.97530	0.25566	0.90132	0.97530	0.99	0.0546	29
	Dry	0.08576	0.96758	0.11551	0.90547	0.96758	0.99	0.0522	29
Yellow-poplar	Green	0.21276	0.94890	0.17525	0.98934	0.94890	0.99	0.0374	78
	Dry	0.09197	0.96733	0.08760	0.97748	0.96733	0.99	0.0469	78
Hard Hardwoods	Green	0.24539	0.94286	0.14508	1.05244	0.94286	0.99	0.0571	338
	Dry	0.13483	0.95272	0.10708	1.00078	0.95272	0.99	0.0601	338
Elm species	Green	0.20468	0.94722	-	-	-	0.99	0.0803	16
	Dry	0.15080	0.89866	-	-	-	0.98	0.1323	16
Hickory species	Green	0.28068	0.91782	0.08565	1.16531	0.91782	0.99	0.0530	22
	Dry	0.16939	0.92285	0.07118	1.10362	0.92285	0.99	0.0494	22
Chestnut oak	Green	0.16876	0.97862	-	-	-	0.99	0.0560	37
	Dry	0.10073	0.98236	-	-	-	0.99	0.0619	37
Scarlet oak	Green	0.31737	0.92003	0.17574	1.04328	0.92003	0.99	0.0313	32
	Dry	0.21155	0.90130	0.13262	0.99868	0.90130	0.99	0.0286	32
South. red oak	Green	0.22863	0.95279	0.25013	0.93404	0.95279	0.99	0.0411	48
	Dry	0.12912	0.95733	0.17157	0.89806	0.95733	0.99	0.0419	48

Continued

Table 12.--Regression equations for estimating green and dry weight of total-stem wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. and total height as independent variables--Continued

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
White oak	Green	0.28438	0.92842	0.15775	1.05130	0.92842	0.99	0.0384	110
	Dry	0.16565	0.93256	0.11510	1.00847	0.93256	0.99	0.0388	110
All Species	Green	0.21945	0.94735	0.14017	1.04082	0.94735	0.99	0.0621	773
	Dry	0.11931	0.94646	0.08196	1.02475	0.94646	0.99	0.0948	773
				TOTAL-STEM WOOD					
Soft Hardwoods	Green	0.14783	0.97129	0.11218	1.02882	0.97129	0.99	0.0537	435
	Dry	0.08088	0.95972	0.05756	1.03064	0.95972	0.99	0.0701	435
Red maple	Green	0.15758	0.96251	0.40998	0.76313	0.96251	0.99	0.0535	32
	Dry	0.08935	0.96308	0.12067	0.90043	0.96308	0.99	0.0575	32
Sweetgum	Green	0.14562	0.97102	0.08131	1.09252	0.97102	0.99	0.0491	236
	Dry	0.06962	0.96819	0.03581	1.10684	0.96819	0.99	0.0551	236
Sycamore	Green	0.16388	0.97998	0.22955	0.90971	0.97998	0.99	0.0560	29
	Dry	0.07862	0.97153	0.10630	0.90864	0.97153	0.99	0.0537	29
Yellow-poplar	Green	0.13679	0.97952	0.12839	0.99272	0.97952	0.99	0.0371	78
	Dry	0.06279	0.99292	0.06915	0.97278	0.99292	0.99	0.0507	78
Hard Hardwoods	Green	0.18378	0.95779	0.10349	1.07753	0.95779	0.99	0.0647	338
	Dry	0.10787	0.95928	0.08026	1.02094	0.95928	0.99	0.0660	338
Elm species	Green	0.15438	0.96864	-	-	-	0.99	0.0819	16
	Dry	0.12080	0.91229	-	-	-	0.98	0.1338	16
Hickory species	Green	0.17701	0.94126	0.03816	1.26121	0.94126	0.99	0.0512	22
	Dry	0.10742	0.94905	0.03601	1.17696	0.94905	0.99	0.0504	22
Chestnut oak	Green	0.11276	1.00300	-	-	-	0.99	0.0601	37
	Dry	0.07167	0.99785	-	-	-	0.99	0.0635	37

Continued

Table 12.--Regression equations for estimating green and dry weight of total-stem wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. and total height as independent variables--Continued

Species or species group	Weight green or dry	Regression equation coefficients					Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
		Trees < 11.0 in d.b.h.[1]		Trees > 11.0 in d.b.h.[2]					
		a'	b	a"	b	c			
Scarlet oak	Green	0.24677	0.93195	0.13788	1.05333	0.93195	0.99	0.0348	32
	Dry	0.17482	0.90509	0.11322	0.99567	0.90509	0.99	0.0323	32
South. red oak	Green	0.15553	0.97454	0.16818	0.95824	0.97454	0.99	0.0422	48
	Dry	0.09471	0.96816	0.12429	0.91149	0.96816	0.99	0.0439	48
White oak	Green	0.18544	0.96281	0.11717	1.05853	0.96281	0.99	0.0418	110
	Dry	0.11755	0.95707	0.08949	1.01394	0.95707	0.99	0.0414	110
All Species	Green	0.16495	0.96370	0.10722	1.05352	0.96370	0.99	0.0642	773
	Dry	0.09425	0.95642	0.06497	1.03400	0.95642	0.99	0.0934	773

[1]Trees < 11.0 inches d.b.h.

$$Y = a'(D^2Th)^b$$

[2]Trees $\geq$ 11.0 inches d.b.h.

$$Y = a''(D^2)^b (Th)^c$$

Where: Y = component weight in pounds
D = tree d.b.h. in inches
Th = tree total height in feet
a', a", b, c = regression coefficients

[3]$\log_{10}$ form

Table 13.--Regression equations for estimating cubic-foot volume of above-stump total-tree wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. and total height as independent variables

Species or species group	Volume wood & bark or wood only	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL TREE					
Soft Hardwoods	Wd&Bk	0.00441	0.93725	0.00207	1.09497	0.93725	0.99	0.0644	435
	Wood	0.00305	0.95911	0.00159	1.09472	0.95911	0.99	0.0651	435
Red maple	Wd&Bk	0.00640	0.89829	0.00222	1.11877	0.89829	0.99	0.0522	32
	Wood	0.00466	0.92037	0.00232	1.06582	0.92037	0.99	0.0492	32
Sweetgum	Wd&Bk	0.00421	0.93574	0.00145	1.15807	0.93574	0.99	0.0562	236
	Wood	0.00284	0.95883	0.00096	1.18585	0.95883	0.99	0.0558	236
Sycamore	Wd&Bk	0.00181	1.04965	0.00669	0.77750	1.04965	0.99	0.0528	29
	Wood	0.00162	1.05601	0.00600	0.78277	1.05601	0.99	0.0541	29
Yellow-poplar	Wd&Bk	0.00536	0.92262	0.00272	1.06368	0.92262	0.99	0.0404	78
	Wood	0.00342	0.95142	0.00236	1.02900	0.95142	0.99	0.0360	78
Hard Hardwoods	Wd&Bk	0.00495	0.93914	0.00130	1.21748	0.93914	0.99	0.0690	338
	Wood	0.00350	0.95472	0.00091	1.23664	0.95472	0.99	0.0698	338
Elm species	Wd&Bk	0.00445	0.95789	-	-	-	0.99	0.0880	16
	Wood	0.00284	0.99024	-	-	-	0.99	0.0749	16
Hickory species	Wd&Bk	0.00491	0.95048	0.00185	1.15410	0.95048	0.99	0.0731	22
	Wood	0.00327	0.96187	0.00092	1.22727	0.96187	0.99	0.0578	22
Chestnut oak	Wd&Bk	0.00338	0.97813	-	-	-	0.99	0.0678	37
	Wood	0.00223	0.99671	-	-	-	0.99	0.0673	37
Scarlet oak	Wd&Bk	0.00407	0.97092	0.00141	1.19181	0.97092	0.98	0.0572	32
	Wood	0.00310	0.97972	0.00104	1.20829	0.97972	0.98	0.0551	32
South. red oak	Wd&Bk	0.00466	0.93718	0.00137	1.19269	0.93718	0.99	0.0445	48
	Wood	0.00320	0.95379	0.00088	1.22217	0.95379	0.99	0.0438	48

Continued

Table 13.--Regression equations for estimating cubic-foot volume of above-stump total-tree wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. and total height as independent variables--Continued

Species or species group	Volume wood & bark or wood only	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
White oak	Wd&Bk	0.00428	0.96050	0.00174	1.14789	0.96050	0.99	0.0512	110
	Wood	0.00283	0.98528	0.00120	1.16313	0.98528	0.99	0.0478	110
All Species	Wd&Bk	0.00470	0.93676	0.00170	1.14888	0.93676	0.99	0.0741	773
	Wood	0.00328	0.95591	0.00125	1.15683	0.95591	0.99	0.0728	773

[1]Trees < 11.0 inches d.b.h.

$$Y = a'(D^2Th)^b$$

[2]Trees ≥ 11.0 inches d.b.h.

$$Y = a''(D^2)^b(Th)^c$$

Where: Y = component volume in cubic feet
D = tree d.b.h. in inches
Th = tree total height in feet
a', a", b, c = regression coefficients

[3]$\log_{10}$ form

Table 14.--Regression equations for estimating cubic-foot volume of total-stem wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. and total height as independent variables

Species or species group	Volume wood & bark or wood only	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL STEM					
Soft Hardwoods	Wd&Bk	0.00355	0.94695	0.00278	0.99773	0.94695	0.99	0.0542	435
	Wood	0.00250	0.96882	0.00207	1.00852	0.96882	0.99	0.0534	435
Red maple	Wd&Bk	0.00402	0.93484	0.00817	0.78674	0.93484	0.99	0.0417	32
	Wood	0.00307	0.95401	0.00734	0.77199	0.95401	0.99	0.0396	32
Sweetgum	Wd&Bk	0.00354	0.94353	0.00245	1.01987	0.94353	0.99	0.0530	236
	Wood	0.00242	0.96703	0.00152	1.06405	0.96703	0.99	0.0509	236
Sycamore	Wd&Bk	0.00240	0.99364	0.00512	0.83607	0.99364	0.99	0.0487	29
	Wood	0.00216	1.00062	0.00466	0.84031	1.00062	0.99	0.0495	29
Yellow-poplar	Wd&Bk	0.00430	0.93475	0.00347	0.97925	0.93475	0.99	0.0400	78
	Wood	0.00298	0.95568	0.00290	0.96153	0.95568	0.99	0.0340	78
Hard Hardwoods	Wd&Bk	0.00412	0.93494	0.00284	1.01304	0.93494	0.99	0.0551	338
	Wood	0.00291	0.95482	0.00193	1.04062	0.95482	0.99	0.0564	338
Elm species	Wd&Bk	0.00362	0.94165	-	-	-	0.99	0.0809	16
	Wood	0.00236	0.97704	-	-	-	0.99	0.0757	16
Hickory species	Wd&Bk	0.00481	0.91795	0.00248	1.05655	0.91795	0.99	0.0539	22
	Wood	0.00313	0.93829	0.00120	1.13843	0.93829	0.99	0.0472	22
Chestnut oak	Wd&Bk	0.00301	0.96996	-	-	-	0.99	0.0588	37
	Wood	0.00200	0.99149	-	-	-	0.99	0.0584	37
Scarlet oak	Wd&Bk	0.00437	0.92917	0.00247	1.04824	0.92917	0.99	0.0327	32
	Wood	0.00323	0.94668	0.00191	1.05621	0.94668	0.99	0.0337	32
South. red oak	Wd&Bk	0.00409	0.93293	0.00329	0.97797	0.93293	0.99	0.0398	48
	Wood	0.00294	0.94612	0.00200	1.02702	0.94612	0.99	0.0368	48

Continued

Table 14.--Regression equations for estimating cubic-foot volume of total-stem wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. and total height as independent variables--Continued

Species or species group	Volume wood & bark or wood only	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
White oak	Wd&Bk	0.00544	0.90256	0.00293	1.03114	0.90256	0.99	0.0387	110
	Wood	0.00347	0.93596	0.00199	1.05198	0.93596	0.99	0.0392	110
All Species	Wd&Bk	0.00382	0.94065	0.00278	1.00702	0.94065	0.99	0.0561	773
	Wood	0.00269	0.96170	0.00199	1.02470	0.96170	0.99	0.0558	773

[1]Trees < 11.0 inches d.b.h.

$Y = a'(D^2Th)^b$

[2]Trees $\geq$ 11.0 inches d.b.h.

$Y = a''(D^2)^b(Th)^c$

Where: Y = component volume in cubic feet
D = tree d.b.h. in inches
Th = tree total height in feet
a', a", b, c = regression coefficients

[3]$\log_{10}$ form

Table 15.--Regression equations for estimating green and dry weight of above-stump total-tree wood, bark, and foliage, wood and bark combined, and wood alone for hardwood species in the Piedmont, with d.b.h. and height to a 4-inch top as independent variables

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
TOTAL-TREE WOOD, BARK, AND FOLIAGE									
Soft Hardwoods	Green	2.90893	0.69841	0.39234	1.11616	0.69841	0.99	0.0538	327
	Dry	1.36096	0.70330	0.19732	1.10597	0.70330	0.98	0.0690	327
Red maple	Green	2.51894	0.71200	0.19554	1.24493	0.71200	0.98	0.0546	24
	Dry	1.35267	0.71551	0.06773	1.33988	0.71551	0.98	0.0559	24
Sweetgum	Green	3.15804	0.68557	0.28003	1.19077	0.68557	0.99	0.0514	175
	Dry	1.38655	0.69333	0.11550	1.21156	0.69333	0.98	0.0587	175
Sycamore	Green	1.32693	0.80787	0.92610	0.88286	0.80787	0.98	0.0581	25
	Dry	0.61941	0.80286	0.40948	0.88915	0.80286	0.98	0.0614	25
Yellow-poplar	Green	2.63970	0.70663	0.38692	1.10702	0.70663	0.99	0.0446	75
	Dry	1.09600	0.72761	0.19264	1.09014	0.72761	0.99	0.0496	75
Hard Hardwoods	Green	2.67031	0.73383	0.22449	1.25015	0.73383	0.98	0.0711	264
	Dry	1.49934	0.73995	0.14185	1.23164	0.73995	0.98	0.0711	264
Elm species	Green	2.39030	0.74495	-	-	-	0.97	0.0633	8
	Dry	2.53891	0.65095	-	-	-	0.84	0.1347	8
Hickory species	Green	2.17151	0.76148	0.22393	1.23520	0.76148	0.97	0.0840	18
	Dry	1.52681	0.74343	0.14348	1.23652	0.74343	0.97	0.0797	18
Chestnut oak	Green	1.92030	0.76073	-	-	-	0.96	0.0686	25
	Dry	1.14467	0.76155	-	-	-	0.97	0.0637	25
Scarlet oak	Green	3.26248	0.72175	0.26987	1.24143	0.72175	0.96	0.0783	32
	Dry	2.02272	0.71235	0.17335	1.22465	0.71235	0.95	0.0825	32
South. red oak	Green	4.08240	0.67268	0.24070	1.26297	0.67268	0.98	0.0608	46
	Dry	2.13886	0.68665	0.15024	1.24042	0.68665	0.99	0.0603	46

Continued

Table 15.--Regression equations for estimating green and dry weight of above-stump total-tree wood, bark, and foliage, wood and bark combined, and wood alone for hardwood species in the Piedmont, with d.b.h. and height to a 4-inch top as independent variables--Continued

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
White oak	Green	1.95422	0.77781	0.29380	1.17291	0.77731	0.99	0.0519	94
	Dry	1.15404	0.77896	0.19005	1.15507	0.77896	0.99	0.0515	94
All Species	Green	2.98907	0.70662	0.31019	1.17903	0.70662	0.97	0.0795	591
	Dry	1.61049	0.70631	0.17278	1.17178	0.70631	0.94	0.1145	591
				TOTAL-TREE WOOD AND BARK					
Soft Hardwoods	Green	2.61299	0.70726	0.36877	1.11555	0.70726	0.99	0.0532	327
	Dry	1.26350	0.70948	0.18696	1.10790	0.70948	0.98	0.0691	327
Red maple	Green	2.30326	0.71766	0.20565	1.22141	0.71766	0.98	0.0504	24
	Dry	1.26326	0.71999	0.07217	1.31686	0.71999	0.98	0.0540	24
Sweetgum	Green	2.79700	0.69641	0.26066	1.19124	0.69641	0.99	0.0521	175
	Dry	1.26765	0.70156	0.10813	1.21483	0.70156	0.98	0.0596	175
Sycamore	Green	1.40524	0.79610	0.88179	0.89326	0.79610	0.98	0.0565	25
	Dry	0.65686	0.79263	0.40134	0.89536	0.79263	0.98	0.0605	25
Yellow-poplar	Green	2.34770	0.71667	0.36267	1.10611	0.71667	0.99	0.0440	75
	Dry	1.03606	0.73186	0.18283	1.09355	0.73186	0.99	0.0503	75
Hard Hardwoods	Green	2.38269	0.74303	0.21752	1.24215	0.74303	0.98	0.0676	264
	Dry	1.38345	0.74616	0.13961	1.22438	0.74616	0.98	0.0683	264
Elm species	Green	2.31863	0.74394	-	-	-	0.97	0.0623	8
	Dry	2.55494	0.64640	-	-	-	0.83	0.1372	8
Hickory species	Green	2.29392	0.74850	0.19491	1.26259	0.74850	0.97	0.0821	16
	Dry	1.57814	0.73516	0.13234	1.25199	0.73516	0.97	0.0788	16
Chestnut oak	Green	1.76370	0.76580	-	-	-	0.97	0.0664	25
	Dry	1.07594	0.76527	-	-	-	0.97	0.0623	25

Continued

Table 15.--Regression equations for estimating green and dry weight of above-stump total-tree wood, bark, and foliage, wood and bark combined, and wood alone for hardwood species in the Piedmont, with d.b.h. and height to a 4-inch top as independent variables--Continued

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
Scarlet oak	Green	2.87006	0.73186	0.25836	1.23392	0.73186	0.97	0.0711	32
	Dry	1.82832	0.71997	0.17283	1.21183	0.71997	0.96	0.0762	32
South. red oak	Green	3.53643	0.68629	0.24601	1.24209	0.68629	0.99	0.0578	46
	Dry	1.94108	0.69542	0.15151	1.22721	0.69542	0.99	0.0583	46
White oak	Green	1.89162	0.77657	0.27041	1.18219	0.77657	0.99	0.0501	94
	Dry	1.13847	0.77668	0.17921	1.16220	0.77668	0.99	0.0502	94
All Species	Green	2.67321	0.71577	0.29531	1.17513	0.71577	0.97	0.0772	591
	Dry	1.48730	0.71273	0.16628	1.16959	0.71273	0.94	0.1126	591
				TOTAL-TREE WOOD					
Soft Hardwoods	Green	1.99542	0.72157	0.30841	1.11091	0.72157	0.98	0.0576	327
	Dry	0.99364	0.72040	0.16015	1.10099	0.72040	0.97	0.0723	327
Red maple	Green	1.88383	0.72444	0.20926	1.18265	0.72444	0.98	0.0473	24
	Dry	1.03086	0.72875	0.06680	1.29935	0.72875	0.98	0.0530	24
Sweetgum	Green	2.08952	0.71391	0.21264	1.19039	0.71391	0.99	0.0524	175
	Dry	0.98670	0.71310	0.09031	1.21169	0.71310	0.98	0.0610	175
Sycamore	Green	1.15994	0.81178	0.80826	0.88711	0.81178	0.98	0.0575	25
	Dry	0.54228	0.80795	0.37989	0.88216	0.80795	0.98	0.0611	25
Yellow-poplar	Green	1.68845	0.73275	0.27766	1.10916	0.73275	0.99	0.0441	75
	Dry	0.79714	0.74243	0.14921	1.09183	0.74243	0.98	0.0530	75
Hard Hardwoods	Green	1.74483	0.75788	0.16471	1.25002	0.75788	0.98	0.0720	264
	Dry	1.02838	0.75937	0.11252	1.22074	0.75937	0.97	0.0736	264
Elm species	Green	1.73930	0.76245	-	-	-	0.98	0.0508	8
	Dry	2.19806	0.64650	-	-	-	0.84	0.1331	8

Continued

Table 15.--Regression equations for estimating green and dry weight of above-stump total-tree wood, bark, and foliage, wood and bark combined, and wood alone for hardwood species in the Piedmont, with d.b.h. and height to a 4-inch top as independent variables--Continued

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
Hickory species	Green	1.39474	0.77236	0.09270	1.33767	0.77236	0.98	0.0768	18
	Dry	0.91832	0.76974	0.07464	1.29310	0.76974	0.97	0.0779	18
Chestnut oak	Green	1.32870	0.77192	-	-	-	0.96	0.0703	25
	Dry	0.84404	0.76625	-	-	-	0.96	0.0707	25
Scarlet oak	Green	2.30200	0.73638	0.19592	1.25012	0.73638	0.97	0.0709	32
	Dry	1.53103	0.71834	0.13986	1.21733	0.71834	0.96	0.0773	32
South. red oak	Green	2.52502	0.70064	0.17384	1.25859	0.70064	0.99	0.0592	46
	Dry	1.47845	0.69999	0.11256	1.23698	0.69999	0.99	0.0606	46
White oak	Green	1.40995	0.79088	0.19790	1.20032	0.79088	0.99	0.0489	94
	Dry	0.89393	0.78533	0.13813	1.17472	0.78533	0.99	0.0486	94
All Species	Green	1.98507	0.73131	0.23687	1.17460	0.73131	0.97	0.0768	591
	Dry	1.12708	0.72574	0.13862	1.16272	0.72574	0.94	0.1090	591

[1] Trees < 11.0 inches d.b.h.

$$Y = a'(D^2H4)^b$$

[2] Trees $\geq$ 11.0 inches d.b.h.

$$Y = a''(D^2)^b\ (H4)^c$$

Where: Y = component weight in pounds
D = tree d.b.h. in inches
H4 = tree height to 4-inch top in feet
a', a", b, c = regression coefficients

[3] $\log_{10}$ form

Table 16.--Regression equations for estimating green and dry weight of total-stem wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. and height to 4-inch top as independent variables

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
TOTAL-STEM WOOD AND BARK									
Soft Hardwoods	Green	2.29156	0.70545	0.42879	1.05493	0.70545	0.99	0.0465	327
	Dry	1.12653	0.70556	0.21669	1.04929	0.70556	0.98	0.0613	327
Red maple	Green	2.22532	0.69908	0.53744	0.99535	0.69908	0.99	0.0322	24
	Dry	1.22695	0.70207	0.16335	1.12252	0.70207	0.98	0.0493	24
Sweetgum	Green	2.50069	0.69517	0.36891	1.09422	0.69517	0.99	0.0494	175
	Dry	1.13379	0.70024	0.15884	1.11005	0.70024	0.98	0.0575	175
Sycamore	Green	1.57648	0.75799	0.59202	0.96221	0.75799	0.99	0.0517	25
	Dry	0.76574	0.74827	0.26378	0.97049	0.74827	0.98	0.0573	25
Yellow-poplar	Green	1.82487	0.73310	0.47036	0.47036	0.73310	0.99	0.0415	75
	Dry	0.80991	0.74909	0.24003	1.00267	0.74909	0.99	0.0465	75
Hard Hardwoods	Green	2.16281	0.72694	0.41701	1.07017	0.72694	0.99	0.0483	264
	Dry	1.26025	0.72959	0.30008	1.02881	0.72959	0.99	0.0498	264
Elm species	Green	2.12287	0.71366	-	-	-	0.99	0.0140	8
	Dry	3.08884	0.57354	-	-	-	0.83	0.1255	8
Hickory species	Green	2.69454	0.69078	0.20666	1.22623	0.69078	0.99	0.0470	18
	Dry	1.86830	0.67878	0.16406	1.18601	0.67878	0.99	0.0497	18
Chestnut oak	Green	1.86199	0.73296	-	-	-	0.98	0.0447	25
	Dry	1.16418	0.73030	-	-	-	0.99	0.0421	25
Scarlet oak	Green	2.59832	0.71047	0.45824	1.07229	0.71047	0.99	0.0323	32
	Dry	1.68022	0.69448	0.33798	1.02888	0.69448	0.99	0.0326	32
South. red oak	Green	2.89546	0.69112	0.62603	1.01046	0.69112	0.99	0.0504	46
	Dry	1.60781	0.69805	0.43698	0.96970	0.69805	0.99	0.0498	46

Continued

Table 16.--Regression equations for estimating green and dry weight of total-stem wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. and height to 4-inch top as independent variables--Continued

Species or species group	Weight green or dry	Regression equation coefficients					Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
		Trees < 11.0 in d.b.h.[1]		Trees > 11.0 in d.b.h.[2]					
		a'	b	a"	b	c			
White oak	Green	1.85973	0.74792	0.43602	1.05037	0.74792	0.99	0.0376	94
	Dry	1.13819	0.74596	0.31297	1.01517	0.74596	0.99	0.0390	94
All Species	Green	2.30521	0.71114	0.42329	1.06454	0.71114	0.98	0.0537	591
	Dry	1.28716	0.70695	0.24850	1.04991	0.70695	0.96	0.0864	591
				TOTAL STEM WOOD					
Soft Hardwoods	Green	1.78632	0.71990	0.35353	1.05769	0.71990	0.99	0.0503	327
	Dry	0.90284	0.71634	0.18369	1.04836	0.71634	0.98	0.0634	327
Red maple	Green	1.80821	0.70999	0.49709	0.97925	0.70999	0.99	0.0294	24
	Dry	1.00466	0.71340	0.14684	1.11439	0.71340	0.98	0.0498	24
Sweetgum	Green	1.89662	0.71354	0.29324	1.10281	0.71354	0.99	0.0501	175
	Dry	0.89637	0.71212	0.12940	1.11570	0.71212	0.98	0.0587	175
Sycamore	Green	1.35267	0.77065	0.54812	0.95902	0.77065	0.99	0.0520	25
	Dry	0.65137	0.76164	0.25165	0.95995	0.76164	0.98	0.0569	25
Yellow-poplar	Green	1.37047	0.74627	0.34989	1.03095	0.74627	0.99	0.0416	75
	Dry	0.64459	0.75718	0.19106	1.01074	0.75718	0.99	0.0491	75
Hard Hardwoods	Green	1.59092	0.74533	0.31390	1.08375	0.74533	0.98	0.0563	264
	Dry	0.93691	0.74626	0.24016	1.03011	0.74626	0.98	0.0580	264
Elm species	Green	1.62361	0.73497	-	-	-	0.99	0.0262	8
	Dry	2.73257	0.57503	-	-	-	0.83	0.1251	8
Hickory species	Green	1.61589	0.72179	0.09578	1.31097	0.72179	0.99	0.0493	18
	Dry	1.08255	0.71766	0.08801	1.24095	0.71766	0.99	0.0524	18
Chestnut oak	Green	1.40117	0.74325	-	-	-	0.98	0.0495	25
	Dry	0.90514	0.73521	-	-	-	0.98	0.0501	25

Continued

Table 16.--Regression equations for estimating green and dry weight of total-stem wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. and height to 4-inch top as independent variables--Continued

Species or species group	Weight green or dry	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
Scarlet oak	Green	2.08324	0.71926	0.36368	1.08321	0.71926	0.99	0.0364	32
	Dry	1.40851	0.69671	0.28924	1.02680	0.69671	0.99	0.0370	32
South. red oak	Green	2.15610	0.70264	0.41914	1.04416	0.70264	0.99	0.0520	46
	Dry	1.26835	0.70020	0.31034	0.99375	0.70020	0.99	0.0522	46
White oak	Green	1.36641	0.76901	0.32466	1.06868	0.76901	0.99	0.0409	94
	Dry	0.87703	0.76125	0.24278	1.02906	0.76125	0.99	0.0410	94
All Species	Green	1.74130	0.72798	0.33623	1.07091	0.72798	0.98	0.0568	591
	Dry	0.98977	0.72110	0.20564	1.04875	0.72110	0.96	0.0850	590

[1]Trees < 11.0 inches d.b.h.

$$Y = a'(D^2H4)^b$$

[2]Trees $\geq$ 11.0 inches d.b.h.

$$Y = a''(D^2)^b\ (H4)^c$$

Where: Y = component weight in pounds
D = tree d.b.h. in inches
H4 = tree height to 4-inch top in feet
a', a", b, c = regression coefficients

[3]$\log_{10}$ form

Table 17.--Regression equations for estimating cubic-foot volume of above-stump total-tree wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. and height to 4-inch top as independent variables

Species or species group	Volume wood & bark or wood only	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL TREE					
Soft Hardwoods	Wd&Bk	0.04446	0.70786	0.00723	1.08651	0.70786	0.99	0.0520	327
	Wood	0.03116	0.72981	0.00593	1.07591	0.72981	0.99	0.0525	327
Red maple	Wd&Bk	0.03705	0.73314	0.00508	1.14743	0.73314	0.98	0.0504	24
	Wood	0.03028	0.74178	0.00509	1.11338	0.74178	0.98	0.0477	24
Sweetgum	Wd&Bk	0.04903	0.69063	0.00534	1.15293	0.69063	0.99	0.0493	175
	Wood	0.03303	0.71611	0.00390	1.16140	0.71611	0.99	0.0491	175
Sycamore	Wd&Bk	0.02214	0.79638	0.01592	0.86513	0.79638	0.98	0.0585	25
	Wood	0.01845	0.81137	0.01472	0.85844	0.81137	0.98	0.0590	25
Yellow-poplar	Wd&Bk	0.04631	0.70449	0.00699	1.09877	0.70449	0.99	0.0418	74
	Wood	0.03560	0.71187	0.00608	1.08041	0.71187	0.99	0.0356	74
Hard Hardwoods	Wd&Bk	0.03763	0.74279	0.00420	1.19992	0.74279	0.98	0.0627	264
	Wood	0.02681	0.75856	0.00303	1.21303	0.75856	0.98	0.0651	264
Elm species	Wd&Bk	0.03373	0.76474	-	-	-	0.96	0.0695	8
	Wood	0.02450	0.78253	-	-	-	0.98	0.0509	8
Hickory species	Wd&Bk	0.04393	0.73463	0.00480	1.19614	0.73463	0.97	0.0800	18
	Wood	0.02599	0.76123	0.00247	1.25199	0.76123	0.98	0.0688	18
Chestnut oak	Wd&Bk	0.02745	0.77407	-	-	-	0.97	0.0631	25
	Wood	0.01999	0.78134	-	-	-	0.97	0.0669	25
Scarlet oak	Wd&Bk	0.04061	0.73977	0.00380	1.23403	0.73977	0.97	0.0678	32
	Wood	0.03151	0.74693	0.00282	1.25037	0.74693	0.97	0.0659	32
South. red oak	Wd&Bk	0.05657	0.67994	0.00336	1.26862	0.67994	0.99	0.0579	46
	Wood	0.04024	0.69298	0.00220	1.29892	0.69298	0.99	0.0585	46

Continued

Table 17.--Regression equations for estimating cubic-foot volume of above-stump total-tree wood and bark cobmined and wood alone for hardwood species in the Piedmont, with d.b.h. and height to 4-inch top as independent variables--Continued

Species or species group	Volume wood & bark or wood only	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
White oak	Wd&Bk	0.02975	0.77467	0.00516	1.13999	0.77467	0.99	0.0476	94
	Wood	0.02127	0.79077	0.00358	1.16247	0.79077	0.99	0.0445	94
All Species	Wd&Bk	0.04300	0.71848	0.00576	1.13779	0.71848	0.98	0.0652	591
	Wood	0.03013	0.73856	0.00447	1.13649	0.73856	0.98	0.0641	591

[1]Trees < 11.0 inches d.b.h.

$$Y = a'(D^2H4)^b$$

[2]Trees $\geq$ 11.0 inches d.b.h.

$$Y = a''(D^2)^b\ (H4)^c$$

Where: Y = component volume in cubic feet
D = tree d.b.h. in inches
H4 = tree height to 4-inch top in feet
a', a", b, c = regression coefficients

[3]$\log_{10}$ form

Table 18.--Regression equations for estimating cubic-foot volume of total-stem wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. and height to 4-inch top as independent variables

Species or species group	Volume wood & bark or wood only	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
				TOTAL STEM					
Soft Hardwoods	Wd&Bk	0.03907	0.70612	0.00887	1.01517	0.70612	0.99	0.0461	327
	Wood	0.02773	0.72879	0.00710	1.01304	0.72879	0.99	0.0434	327
Red maple	Wd&Bk	0.03279	0.72602	0.01353	0.91057	0.72602	0.99	0.0282	24
	Wood	0.02656	0.73901	0.01235	0.89862	0.73901	0.99	0.0260	24
Sweetgum	Wd&Bk	0.04392	0.68974	0.00827	1.03783	0.68974	0.99	0.0481	175
	Wood	0.02981	0.71653	0.00576	1.05919	0.71653	0.99	0.0478	175
Sycamore	Wd&Bk	0.02603	0.75115	0.01091	0.93239	0.75115	0.99	0.0513	25
	Wood	0.02258	0.76287	0.01021	0.92846	0.76287	0.99	0.0508	25
Yellow-poplar	Wd&Bk	0.03569	0.72218	0.00917	1.00549	0.72218	0.99	0.0420	75
	Wood	0.02864	0.72644	0.00770	1.00040	0.72644	0.99	0.0349	75
Hard Hardwoods	Wd&Bk	0.03434	0.72578	0.00825	1.02317	0.72578	0.99	0.0445	264
	Wood	0.02465	0.74494	0.00582	1.04584	0.74494	0.99	0.0497	264
Elm species	Wd&Bk	0.03122	0.73147	-	-	-	0.99	0.0174	8
	Wood	0.02290	0.75482	-	-	-	0.99	0.0281	8
Hickory species	Wd&Bk	0.05130	0.67784	0.00580	1.13323	0.67784	0.99	0.0484	18
	Wood	0.02948	0.71470	0.00296	1.19380	0.71470	0.99	0.0452	18
Chestnut oak	Wd&Bk	0.02915	0.74106	-	-	-	0.98	0.0462	25
	Wood	0.02092	0.75438	-	-	-	0.98	0.0487	25
Scarlet oak	Wd&Bk	0.03696	0.71620	0.00649	1.07908	0.71620	0.99	0.0360	32
	Wood	0.02850	0.72923	0.00510	1.08817	0.72923	0.99	0.0378	32
South. red oak	Wd&Bk	0.04688	0.68265	0.00832	1.04325	0.68265	0.99	0.0494	46
	Wood	0.03539	0.69066	0.00504	1.09694	0.69066	0.99	0.0487	46

Continued

Table 18.--Regression equations for estimating cubic-foot volume of total-stem wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. and height to 4-inch top as independent variables--Continued

Species or species group	Volume wood & bark or wood only	Regression equation coefficients: Trees < 11.0 in d.b.h.[1] a'	b	Trees > 11.0 in d.b.h.[2] a"	b	c	Coefficient of determination (R^2)	Standard error[3] ($S_{y.x}$)	No. of trees sampled
White oak	Wd&Bk	0.03008	0.74210	0.00848	1.00605	0.74210	0.99	0.0348	94
	Wood	0.02110	0.76553	0.00583	1.03378	0.76553	0.99	0.0359	94
All Species	Wd&Bk	0.03725	0.71359	0.00861	1.01890	0.71359	0.99	0.0460	591
	Wood	0.02650	0.73508	0.00654	1.02694	0.73508	0.99	0.0466	591

[1]Trees < 11.0 inches d.b.h.

$$Y = a'(D^2H4)^b$$

[2]Trees $\geq$ 11.0 inches d.b.h.

$$Y = a''(D^2)^b\ (H4)^c$$

Where: Y = component volume in cubic feet
D = tree d.b.h. in inches
H4 = tree height to 4-inch top in feet
a', a", b, c = regression coefficients

[3]$\log_{10}$ form

Table 19.--Regression equations for estimating green and dry weight of above-stump total-tree wood, bark, and foliage, wood and bark combined, and wood alone for hardwood species in the Piedmont, with d.b.h. and saw-log merchantable height as independent variables

Species or species group	Weight green or dry	Regression equation coefficients[1] a	b	c	Coefficient of determination (R^2)	Standard error[2] ($S_{y.x}$)	No. of trees sampled
TOTAL-TREE WOOD, BARK, AND FOLIAGE							
oft Hardwoods	Green	6.16340	1.06181	0.14075	0.88	0.0657	123
	Dry	3.30431	1.10629	0.04676	0.86	0.0685	123
Sweetgum	Green	4.82876	1.12408	0.11727	0.91	0.0552	56
	Dry	3.08628	1.12057	0.14936	0.90	0.0600	56
Sycamore	Green	39.67031	0.55215	0.41342	0.86	0.0657	15
	Dry	20.92329	0.49255	0.45743	0.83	0.0734	15
Yellow-poplar	Green	3.69070	1.12441	0.17196	0.92	0.0585	40
	Dry	2.27508	1.15141	0.07477	0.90	0.0627	40
ard Hardwoods	Green	2.71418	1.25757	0.12847	0.88	0.0660	98
	Dry	1.74397	1.24211	0.12634	0.87	0.0697	98
Scarlet oak	Green	5.14653	1.25279	-0.06827	0.97	0.0348	16
	Dry	4.51906	1.22648	-0.15867	0.96	0.0399	16
South. red oak	Green	5.74229	1.13955	0.07902	0.92	0.0502	24
	Dry	3.42939	1.13834	0.07467	0.91	0.0531	24
White oak	Green	1.63124	1.39157	0.06708	0.93	0.0555	38
	Dry	1.06912	1.37123	0.06905	0.92	0.0597	38
ll Species	Green	4.90783	1.19288	0.02969	0.84	0.0766	221
	Dry	3.31791	1.23516	-0.10229	0.74	0.1022	221
TOTAL-TREE WOOD AND BARK							
oft Hardwoods	Green	5.93717	1.05516	0.15325	0.88	0.0652	123
	Dry	3.16814	1.10332	0.05787	0.87	0.0682	123
Sweetgum	Green	4.80892	1.11113	0.13135	0.91	0.0557	56
	Dry	2.04258	1.11675	0.15718	0.90	0.0603	56
Sycamore	Green	36.02956	0.55628	0.42159	0.86	0.0667	15
	Dry	19.40042	0.49456	0.46638	0.83	0.0741	15
Yellow-poplar	Green	3.70426	1.11862	0.17242	0.92	0.0579	40
	Dry	2.23925	1.15166	0.07463	0.90	0.0629	40
ard Hardwoods	Green	2.63369	1.24969	0.13904	0.88	0.0656	98
	Dry	1.68788	1.23604	0.13690	0.87	0.0690	98
carlet oak	Green	4.34704	1.24727	-0.02093	0.97	0.0320	16
	Dry	3.97479	1.21788	-0.11805	0.96	0.0371	16

Continued

able 19.--Regression equations for estimating green and dry weight of above-stump total-tree wood, bark, nd foliage, wood and bark combined, and wood alone for hardwood species in the Piedmont, with d.b.h. nd saw-log merchantable height as independent variables--Continued

Species or species group	Weight green or dry	Regression equation coefficients[1] a	b	c	Coefficient of determination (R^2)	Standard error[2] ($S_{y.x}$)	No. of trees sampled
South. red oak	Green	5.81860	1.12812	0.08277	0.92	0.0497	24
	Dry	3.45717	1.13251	0.07353	0.92	0.0519	24
White oak	Green	1.56640	1.38649	0.07660	0.94	0.0547	38
	Dry	1.01472	1.36833	0.08063	0.93	0.0584	38
ll Species	Green	4.71974	1.18466	0.04426	0.84	0.0755	221
	Dry	3.17469	1.22898	-0.08704	0.74	0.1005	221
			TOTAL-TREE WOOD				
oft Hardwoods	Green	5.33812	1.03469	0.17425	0.85	0.0735	123
	Dry	2.95691	1.08784	0.06027	0.85	0.0722	123
Sweetgum	Green	4.26547	1.10159	0.14174	0.91	0.0566	56
	Dry	1.85726	1.11531	0.14506	0.90	0.0612	56
Sycamore	Green	34.88147	0.55564	0.41726	0.85	0.0685	15
	Dry	18.88130	0.49271	0.46035	0.82	0.0769	15
Yellow-poplar	Green	2.84055	1.14182	0.16022	0.92	0.0577	40
	Dry	1.85316	1.18335	0.03324	0.90	0.0615	40
ard Hardwoods	Green	1.91965	1.25217	0.17663	0.86	0.0721	98
	Dry	1.27266	1.23388	0.17000	0.84	0.0779	98
Scarlet oak	Green	3.07600	1.25572	0.01875	0.97	0.0321	16
	Dry	3.12229	1.21079	-0.08963	0.96	0.0376	16
South. red oak	Green	4.00847	1.13728	0.11847	0.91	0.0544	24
	Dry	2.41552	1.12809	0.11878	0.90	0.0582	24
White oak	Green	1.30013	1.38510	0.08872	0.93	0.0557	38
	Dry	0.87537	1.36221	0.08849	0.92	0.0590	38
ll Species	Green	3.89404	1.16792	0.07993	0.83	0.0798	221
	Dry	2.72403	1.20958	-0.06022	0.74	0.0998	221

$Y = a(D^2)^b (Mh)^c$

Where: Y = component weight in pounds
D = tree d.b.h. in inches
Mh = tree saw-log merchantable height in feet
a,b,c = regression coefficients

$\log_{10}$ form

0

Table 20.--Regression equations for estimating green and dry weight of saw-log merchantable-stem wood and bark combined and wood alone for hard-wood species in the Piedmont, with d.b.h. and saw-log merchantable height as independent variables

Species or species group	Weight green or dry	Regression equation coefficients[1] a	b	c	Coefficient of determination (R^2)	Standard error[2] ($S_{y.x}$)	No. of trees sampled
		SAW-LOG STEM WOOD AND BARK					
Soft Hardwoods	Green	0.67595	0.89328	0.85866	0.97	0.0430	123
	Dry	0.36620	0.94121	0.75877	0.96	0.0522	123
Sweetgum	Green	0.65236	0.96221	0.77262	0.97	0.0441	56
	Dry	0.28174	0.95355	0.81101	0.96	0.0476	56
Sycamore	Green	1.38050	0.75171	0.87234	0.97	0.0469	15
	Dry	0.73990	0.66517	0.95000	0.97	0.0537	15
Yellow-poplar	Green	0.55649	0.94770	0.82697	0.98	0.0362	40
	Dry	0.33553	0.98999	0.71972	0.96	0.0479	40
Hard Hardwoods	Green	0.38692	1.08711	0.76368	0.97	0.0368	98
	Dry	0.25507	1.05649	0.77399	0.96	0.0400	98
Scarlet oak	Green	0.28236	1.16022	0.76264	0.98	0.0274	16
	Dry	0.29759	1.10027	0.66135	0.97	0.0299	16
South. red oak	Green	0.49344	1.00035	0.80825	0.98	0.0328	24
	Dry	0.29400	0.98681	0.81718	0.98	0.0360	24
White oak	Green	0.35004	1.11465	0.75103	0.98	0.0288	38
	Dry	0.23828	1.07714	0.76684	0.98	0.0317	38
All Species	Green	0.55409	1.02467	0.73488	0.95	0.0520	221
	Dry	0.38056	1.05605	0.61383	0.88	0.0800	221
		SAW-LOG STEM WOOD					
Soft Hardwoods	Green	0.61760	0.89024	0.85859	0.97	0.0487	123
	Dry	0.35161	0.93806	0.74302	0.96	0.0527	123
Sweetgum	Green	0.59993	0.96725	0.76266	0.97	0.0441	56
	Dry	0.26906	0.96144	0.78172	0.96	0.0472	56
Sycamore	Green	1.31571	0.75985	0.86343	0.97	0.0489	15
	Dry	0.70847	0.67292	0.93861	0.96	0.0566	15
Yellow-poplar	Green	0.42342	0.99036	0.79729	0.98	0.0379	40
	Dry	0.27854	1.04004	0.65748	0.96	0.0492	40
Hard Hardwoods	Green	0.29767	1.09847	0.78450	0.95	0.0467	98
	Dry	0.20003	1.06247	0.79412	0.93	0.0535	98

Continued

Table 20.--Regression equations for estimating green and dry weight of saw-log merchantable-stem wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. and saw-log merchantable height as independent variables--Continued

Species or species group	Weight green or dry	Regression equation coefficients[1] a	b	c	Coefficient of determination (R^2)	Standard error[2] ($S_{y.x}$)	No. of trees sampled
Scarlet oak	Green	0.23242	1.16362	0.77546	0.98	0.0315	16
	Dry	0.27482	1.08420	0.66505	0.97	0.0340	16
South. red oak	Green	0.36379	1.00704	0.83888	0.97	0.0371	24
	Dry	0.21906	0.97487	0.86472	0.97	0.0412	24
White oak	Green	0.31177	1.12038	0.74633	0.98	0.0315	38
	Dry	0.21647	1.08001	0.75892	0.98	0.0340	38
All Species	Green	0.47426	1.02196	0.74970	0.95	0.0557	221
	Dry	0.33963	1.04751	0.62258	0.89	0.0785	221

[1] $Y = a(D^2)^b(Mh)^c$

Where: Y = component weight in pounds
D = tree d.b.h. in inches
Mh = tree saw-log merchantable height in feet
a,b,c = regression coefficients

[2] $\log_{(}$ for $)$

Table 21.--Regression equations for estimating cubic-foot volume of above-stump total-tree wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. and saw-log merchantable height as independent variables

Species or species group	Volume wood & bark or wood only	Regression equation coefficients[1] a	b	c	Coefficient of determination (R^2)	Standard error[2] ($S_{y.x}$)	No. of trees sampled
			TOTAL TREE				
Soft Hardwoods	Wd&Bk	0.10552	1.05509	0.13692	0.89	0.0626	23
	Wood	0.09583	1.03585	0.14745	0.88	0.0656	123
Sweetgum	Wd&Bk	0.09775	1.01130	0.21776	0.91	0.0557	56
	Wood	0.08117	1.01485	0.21996	0.91	0.0558	56
Sycamore	Wd&Bk	0.78170	0.52890	0.37297	0.87	0.0596	15
	Wood	0.76002	0.52710	0.36990	0.86	0.0611	15
Yellow-poplar	Wd&Bk	0.06004	1.08702	0.24020	0.92	0.0589	40
	Wood	0.05114	1.09195	0.21951	0.93	0.0539	40
Hard Hardwoods	Wd&Bk	0.05063	1.22643	0.10976	0.89	0.0620	98
	Wood	0.03736	1.22635	0.14310	0.88	0.0640	98
Scarlet oak	Wd&Bk	0.08119	1.22826	-0.05300	0.99	0.0224	16
	Wood	0.05943	1.22990	-0.01528	0.99	0.0204	16
South. red oak	Wd&Bk	0.10323	1.15006	0.00785	0.95	0.0398	24
	Wood	0.07019	1.16638	0.03432	0.95	0.0404	24
White oak	Wd&Bk	0.02510	1.36610	0.08975	0.93	0.0550	38
	Wood	0.02019	1.36957	0.09664	0.93	0.0549	38
All Species	Wd&Bk	0.08168	1.15697	0.06573	0.88	0.0654	221
	Wood	0.06856	1.13968	0.09215	0.87	0.0668	221

[1] $Y = a(D^2)^b(Mh)^c$

Where: Y = component volume in cubic feet
D = tree d.b.h. in inches
Mh = saw-log merchantable height in feet
a,b,c = regression coefficients

[2] $\log_{10}$ form

Table 22.--Regression equations for estimating cubic-foot volume of saw-log merchantable-stem wood and bark combined and wood alone for hardwood species in the Piedmont, with d.b.h. and saw-log merchantable height as independent variables

Species or species group	Volume wood & bark or wood only	Regression equation coefficients[1] a	b	c	Coefficient of determination (R^2)	Standard error[2] ($S_{y.x}$)	Number trees sampled (N)
			SAW-LOG STEM				
Soft Hardwoods	Wd&Bk	0.01266	0.88987	0.83274	0.97	0.0431	121
	Wood	0.01179	0.89346	0.81166	0.98	0.0388	121
Sweetgum	Wd&Bk	0.01485	0.79949	0.91861	0.96	0.0434	55
	Wood	0.01307	0.84055	0.86088	0.97	0.0424	55
Sycamore	Wd&Bk	0.02732	0.71993	0.85113	0.99	0.0316	15
	Wood	0.02618	0.72769	0.84192	0.99	0.0329	15
Yellow-poplar	Wd&Bk	0.01022	0.90924	0.87248	0.98	0.0362	40
	Wood	0.00871	0.94012	0.82258	0.98	0.0339	40
Hard Hardwoods	Wd&Bk	0.00874	1.04386	0.71872	0.97	0.0340	96
	Wood	0.00631	1.06217	0.74366	0.97	0.0365	96
Scarlet oak	Wd&Bk	0.00519	1.14668	0.72612	0.98	0.0258	16
	Wood	0.00457	1.14295	0.73007	0.98	0.0268	16
South. red oak	Wd&Bk	0.01310	1.01034	0.63959	0.98	0.0262	22
	Wood	0.00702	1.04172	0.72127	0.98	0.0277	22
White oak	Wd&Bk	0.00574	1.07881	0.77957	0.98	0.0279	38
	Wood	0.00496	1.09295	0.76519	0.98	0.0293	38
All Species	Wd&Bk	0.01076	0.98684	0.73947	0.96	0.0421	217
	Wood	0.00905	0.98897	0.74695	0.97	0.0398	217

[1] $Y = a(D^2)^b(Mh)^c$

Where: Y = component volume in cubic feet
D = tree d.b.h. in inches
Mh = saw-log merchantable height in feet
a,b,c = regression coefficients

[2] $\log_{10}$ form

Table 23.--Regression coefficients for estimating above-stump stem weight to a specified d.o.b. top diameter as a proportion of total-stem weight for hardwood species in the Piedmont

Species	Regression equation and coefficients[1] $Y_R = e^{a(d)^b (D)^c}$					
	Green weight			Dry weight		
	a	b	c	a	b	c
			WOOD AND BARK			
Soft Hardwoods	-1.73265	4.21073	-4.28793	-1.61846	4.16572	-4.21583
Red maple	-0.80857	4.37677	-4.10402	-0.76750	4.32891	-4.04315
Sweetgum	-1.88706	4.09280	-4.20271	-1.70312	4.00522	-4.07778
Sycamore	-2.31104	4.80579	-4.88417	-2.30869	4.75038	-4.83810
Yellow-poplar	-1.72938	3.99726	-4.17198	-1.76210	4.04115	-4.21537
Hard Hardwoods	-2.61988	3.92928	-4.33719	-2.48096	3.90016	-4.28540
Elm	-5.22488	4.41024	-4.91101	-1.85693	4.17785	-4.19195
Hickory	-9.21973	4.07639	-5.02575	-8.75055	4.05001	-4.97494
Chestnut oak	-1.26318	4.69218	-4.69208	-1.21241	4.73014	-4.70501
Scarlet oak	-4.43019	3.68458	-4.45247	-4.07170	3.59590	-4.33080
South. red oak	-2.08555	3.49897	-3.80231	-1.99820	3.47308	-3.75484
White oak	-1.99440	3.91077	-4.20029	-1.91277	3.93041	-4.19809
All Species	-2.25900	4.00280	-4.27579	-2.10544	3.94825	-4.19553
			WOOD ONLY			
Soft Hardwoods	-1.64304	4.32869	-4.38440	-1.55017	4.23574	-4.27228
Red maple	-0.76381	4.44935	-4.15466	-0.73261	4.36080	-4.05919
Sweetgum	-1.80721	4.20995	-4.30469	-1.65108	4.08554	-4.15193
Sycamore	-2.25912	4.86204	-4.92667	-2.28046	4.80799	-4.88602
Yellow-poplar	-1.64012	4.11183	-4.26807	-1.71038	4.11441	-4.28158
Hard Hardwoods	-2.62600	4.03635	-4.44620	-2.49497	3.99040	-4.37918
Elm	-5.21153	4.60413	-5.10528	-0.56432	3.52387	-3.07702
Hickory	-9.20982	4.13856	-5.09267	-8.62935	4.08077	-5.00432
Chestnut oak	-1.23570	4.86497	-4.85131	-1.19487	4.87213	-4.83716
Scarlet oak	-4.47632	3.79397	-4.56449	-4.08401	3.68907	-4.42364
South. red oak	-2.16525	3.56959	-3.89161	-2.07378	3.53706	-3.83789
White oak	-1.90161	4.04669	-4.31484	-1.85655	4.04282	-4.29760
All Species	-2.21362	4.11130	-4.37739	-2.06611	4.02166	-4.26466

[1]Where: Y_R = stem weight to top d.o.b./total-stem weight ratio
d = stem specified top d.o.b. in inches
D = tree d.b.h. in inches
a,b,c = regression coefficients
e = 2.71828 (base of log E)

Table 24.--Regression coefficients for estimating above-stump stem volume to a specified d.o.b. top diameter as a proportion of total-stem volume for hardwood species in the Piedmont

Species	Regression equation and coefficients[1] $Y_R = e^{a(d)^b (D)^c}$					
	Wood and bark			Wood only		
	a	b	c	a	b	c
Soft Hardwoods	-1.65202	4.16510	-4.23243	-1.17897	4.26410	-4.18729
Red maple	-0.63491	4.07791	-3.74763	-0.72033	4.38479	-4.07700
Sweetgum	-1.71771	4.08636	-4.16133	-1.09648	4.18535	-4.06573
Sycamore	-2.51196	4.72070	-4.84581	-1.47346	4.87589	-4.76297
Yellow-poplar	-1.76181	3.97649	-4.16652	-1.58270	4.11066	-4.25600
Hard Hardwoods	-2.69221	3.89875	-4.32412	-1.58802	3.89439	-4.10976
Elm	-5.53946	4.23262	-4.74180	-2.34516	4.07233	-4.26508
Hickory	-9.21460	4.04604	-4.99672	-9.06779	4.18420	-5.12879
Chestnut oak	-1.38721	4.89309	-4.91657	-1.37476	5.16760	-5.17706
Scarlet oak	-4.61107	3.52799	-4.33254	-4.63561	3.61479	-4.42350
South. red oak	-2.20401	3.43172	-3.77125	-1.47631	3.48332	-3.66336
White oak	-2.17082	3.89490	-4.21939	-1.47760	4.03096	-4.19762
All Species	-2.21693	3.94846	-4.22458	-1.40712	4.02485	-4.10951

[1]Where: Y_R = stem volume to top d.o.b./total-stem volume ratio

d = stem specified top d.o.b. in inches

D = tree d.b.h. in inches

a,b,c = regression coefficients

e = 2.71828 (base of log E)

Table 25.--Regression coefficients for estimating stem weight to a specified d.o.b. top diameter as a proportion of saw-log stem weight for hardwood species in the Piedmont

Species	Ratio equation and coefficients[1] $Y_R = e^{a(Mh)^b((1-(\frac{d}{.78D})^2)^2)^c}$					
	Green weight			Dry weight		
	a	b	c	a	b	c
			WOOD AND BARK			
Soft Hardwoods	34.56311	-1.33687	0.34540	36.21735	-1.34421	0.34571
Sweetgum	22.04668	-1.20280	0.38433	26.47795	-1.24399	0.37862
Sycamore	7.67301	-0.86241	0.34220	10.50581	-0.94737	0.33595
Yellow-poplar	39.47929	-1.42104	0.35509	53.62409	-1.50445	0.34681
Hard Hardwoods	22.66546	-1.26307	0.36865	24.38559	-1.28056	0.37474
Scarlet oak	31.73326	-1.46549	0.36536	40.61327	-1.53417	0.38247
South. red oak	12.89559	-1.07185	0.34506	15.08843	-1.11120	0.35535
White oak	27.61815	-1.33589	0.34312	30.11002	-1.35715	0.35120
All Species	29.74533	-1.31912	0.35749	31.51398	-1.33074	0.36034
			WOOD ONLY			
Soft Hardwoods	35.62364	-1.35443	0.34231	37.33020	-1.36146	0.34311
Sweetgum	22.10232	-1.21539	0.38254	26.88392	-1.26047	0.37755
Sycamore	7.28473	-0.85025	0.34122	10.05026	-0.93713	0.33558
Yellow-poplar	39.90690	-1.43386	0.35307	53.66090	-1.51241	0.34454
Hard Hardwoods	22.47899	-1.26624	0.36449	22.69238	-1.26472	0.36656
Scarlet oak	30.44735	-1.45626	0.36327	29.27276	-1.43826	0.36488
South. red oak	12.83823	-1.07783	0.34287	13.33679	-1.08426	0.34322
White oak	27.40217	-1.33931	0.33906	27.27263	-1.33482	0.33971
All Species	30.20095	-1.33096	0.35380	31.29464	-1.33593	0.35547

[1]Where: Y_R = ratio of stem weight or volume to top d.o.b. saw-log stem

Mh = saw-log merchantable height in feet

d = stem specified top diameter in inches

D = tree d.b.h. in inches

.78 = constant based on average form class

a,b,c = regression coefficients

e = 2.71828 (base of log E)

Table 26.--Regression coefficients for estimating stem volume to a specified d.o.b. top diameter as a proportion of saw-log stem volume for hardwood species in the Piedmont

Species	Ratio equation and coefficients[1] $Y_R = e^{a(Mh)^b((1-(\frac{d}{.78D})^2)^2)^c}$					
	Wood and bark			Wood only		
	a	b	c	a	b	c
Soft Hardwoods	30.25414	-1.30210	0.35021	30.74283	-1.31681	0.34772
Sweetgum	18.57750	-1.15490	0.38851	18.42347	-1.16620	0.38709
Sycamore	7.50334	-0.86564	0.34172	7.01438	-0.85009	0.33987
Yellow-poplar	32.37729	-1.37255	0.36225	31.45762	-1.37480	0.36010
Hard Hardwoods	21.59218	-1.25535	0.37171	21.07918	-1.25541	0.36717
Scarlet oak	32.87656	-1.48776	0.36335	29.65145	-1.46143	0.36113
South. red oak	10.39703	-1.01780	0.34439	10.16607	-1.02040	0.34157
White oak	27.13415	-1.33679	0.34275	26.38838	-1.33583	0.33833
All Species	26.87548	-1.29436	0.36165	26.90075	-1.30344	0.35830

[1]Where: Y_R = ratio of stem weight or volume to top d.o.b. saw-log stem

Mh = saw-log merchantable height in feet

d = stem specified top diameter in inches

D = tree d.b.h. in inches

.78 = constant based on average form class

a,b,c = regression coefficients

e = 2.71828 (base of log E)

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Clark, Alexander, III; Phillips, Douglas R.; Frederick, Douglas J.
Weight, volume, and physical properties of major hardwood species in the Piedmont. Res. Pap. SE-255. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1985. 78 pp.

The weight, volume, and physical properties of trees 1 to 20 inches d.b.h. were determined for red maple, sweetgum, sycamore, yellow-poplar, elm, hickory, chestnut oak, scarlet oak, southern red oak, and white oak in the Piedmont. Hard hardwoods, soft hardwoods, and individual species equations are presented for predicting green and dry weight and green volume of the total tree above stump and its components by using d.b.h. and total height, d.b.h. and height to a 4-inch top, d.b.h. and saw-log merchantable height, and d.b.h. alone. Average specific gravity, moisture content, and weight per cubic foot of wood, bark, and wood and bark combined are presented for each species by tree size class and component. Bark percentage is also presented for each species by tree size class and component.

Keywords: Biomass, equations, specific gravity, moisture content, bark percentage, weight per cubic foot.

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Keywords: Biomass, equations, specific gravity, moisture content, bark percentage, weight per cubic foot.

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An Atmospheric Dispersion Index for Prescribed Burning

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ABSTRACT

A numerical index that estimates the atmosphere's capacity to disperse smoke from prescribed burning is described. The physical assumptions and mathematical development of the index are described in detail. The index is expressed as a positive integer in such a way that doubling the index implies a doubling of the estimated atmospheric capacity. The dispersion index is conceptually similar to ventilation factor but is better able to describe diurnal changes within the lower atmosphere. The index provides a guide to the effect of prescribed burning activity on atmospheric smoke concentration during a portion of a day. The index does not replace smoke dispersion models designed to analyze smoke concentration from individual fires at specific locations, nor does it describe smoke effects on visibility.

Keywords: Smoke management, air pollution potential, ventilation factor, Gaussian dispersion, mesoscale air-quality estimation, Pasquill stability class, area pollution sources.

The effect of human activities on air quality is closely related to the rate of dispersion of pollutants within the atmosphere. Most polluting activity, such as automobile traffic, manufacturing, or power generation, generally takes place with minimal attention to the varying capacity of the atmosphere to dilute pollutants to acceptable levels. Exceptions occur when air-pollution episodes create the need for reduced polluting activity, but in most areas such episodes are rare. Although there is an association between some polluting activities (such as heating and power generation) and weather variables (chiefly temperature), very few are directly associated with atmospheric dispersion rate.

An association between dispersion rate and a significant polluting activity, such as prescribed burning, might be expected--particularly when smoke management is being practiced. Prescribed fires, which represent a temporary source of pollution, can be successfully conducted only under certain weather conditions (Mobley and others 1978). Windspeed, both near the ground and aloft, is an important determinant of both fire behavior and smoke concentrations. Much of the range of weather conditions acceptable for forestry prescribed burning overlaps with that associated with good dispersion of pollutants, so that with proper management neither the smoke nor the fire will be a hazard. Unlike most human polluting activities, prescribed fires can be conducted or allocated on a day-by-day basis according to prevailing and forecast weather conditions.

Some of the guidelines needed for smoke management have been published in "Southern Forestry Smoke Management Guidebook" (Southern Forest Fire Laboratory Staff (SFFLS) 1976) and the FWIS "User Manual" (Paul and Clayton 1978). By use of look-up tables or interactive computer programs, these publications offer adaptations of U.S. Environmental Protection Agency (EPA) models for use in calculating ground-level downwind smoke concentrations from a low-intensity prescribed fire in specified forest fuels. These models are designed for single-fire smoke management to help assure that individual fires are conducted a safe distance from a highway or town. The models become increasingly awkward and expensive to use as the number of sources (fires) and receptors (smoke-sensitive areas) in the computational process rises. If many fires are conducted in a given region, the atmosphere may be overloaded with smoke even if the available models do not indicate a problem from any one fire. Where prescribed fire is intensively used, there is a need to coordinate burning activity based on current and forecast weather conditions to avoid regional smoke overload. Some States, including Oregon, North Carolina, and Florida, have adapted smoke management systems that allow or, in some cases, allocate burning activity based on a weather categorization scheme. For example, the Oregon smoke management system, which has been largely adapted by several Southeastern States, categorizes permissible burning activity

according to ventilation factor (the product of mixing height and transport windspeed). The ventilation factor represents the atmosphere's ultimate dispersion capacity at a given time, which in some cases is a logical basis for regional smoke management. However, the ultimate dispersion capacity of the atmosphere is not always attained due to relatively low dispersion rates within the mixing layer. Also, the ventilation factor is not easily related to dispersion under stable conditions when the mixing height is effectively zero. This Paper proposes an atmospheric dispersion index that takes dispersion rate as well as capacity into account and can be used in unstable, stable, or neutral conditions.

Dispersion Rate--
The Pasquill-Gifford-Turner Stability Classification System

The rate of pollutant dispersion within the atmosphere is largely dependent on stability. Atmospheric stability is determined by the rate of temperature change with respect to height within the atmosphere. A dry atmosphere that cools at a rate in excess of about 0.01 K m^{-1} (5.5 °F per 1,000 ft) is unstable; one that cools at a lesser rate or which becomes warmer with height is stable. Direct measurements of temperature with height are not routinely available except at widely separated upper-air observing stations on a twice-daily basis. There is no clear-cut relationship between dispersion rate and temperature changes with height, given an unstable atmosphere. The air tends to rapidly turn over, given an initial impetus, in an attempt to readjust an unstable temperature profile to a more neutral one. Hence, a measured unstable temperature profile tends to reflect local factors, such as friction within the atmosphere near the ground and the thermal properties of the soil or vegetative cover, more than dispersion rate (Gifford 1975). Because of the difficulties in obtaining and, in some cases, interpreting temperature profiles, the atmospheric dispersion rate near the ground has often been indirectly estimated by use of readily observed weather variables such as surface windspeed, cloud cover, ceiling height, and insolation. The most common estimation scheme is that of Pasquill (1961, 1974), modified by Gifford (1962), and reformulated for computerized applications by Turner (1961, 1964). This scheme assigns a dispersion rate to the lower atmosphere according to one of seven stability classes ranging from extremely unstable through neutral to extremely stable. The class is determined from solar elevation angle, windspeed, opaque cloud cover, and cloud ceiling height. Details for estimating the stability class are given in appendix A. As can be seen from the procedure, the atmosphere tends to be unstable or neutral during the day and stable or neutral at night. Neutral conditions are most likely during cloudy or windy regimes.

Dispersion Capacity--
Mixing Height and Transport Windspeed

The dispersion rate, estimated by use of stability class, generally occurs only within the lower atmosphere at and below the mixing height. Above the mixing height, the dispersion rate is typically very low. The net effect of dispersion at a slow rate overlaying dispersion at a much faster rate near the ground is to create the appearance of a "lid" within the atmosphere, below which most ground pollutants are trapped. The mixing height changes markedly during the course of the day. On a clear night with light winds, the dispersion rate near the ground, particularly in rural areas, may be about as slow as that at great heights. In such conditions, the mixing height is effectively zero, and pollutants spread very slowly above the ground. After sunrise, the ground heats up and the lower atmosphere is warmed from below, creating a mixing layer that typically increases in depth (increasing mixing height) until early afternoon. The mixing height generally reaches a steady state through the afternoon hours until about sunset. By dark, cooling temperatures at ground level create a

stable layer of air that traps ground pollutants, and the mixing height effectively returns to zero. During cloudy or very windy days, the above trends generally do not hold; the mixing height may be determined by frontal zones or other factors that may be rapidly changing as a storm system moves across an area.

During fair weather regimes, when most prescribed fires are conducted, mixing height can be determined fairly accurately by comparing the current surface air temperatures with the upper-air temperature profile measured during early morning hours (1200 G.m.t. or 0700 e.s.t.) (Holzworth 1972). During the day, the surface temperature will typically be higher than that given as surface temperature within the early morning upper-air profile. By comparing the temperatures and pressures of the surface and upper-air observations and assuming a dry adiabatic process of atmospheric mixing (Hess 1959), the mixing height associated with the current surface temperature can be ascertained. The smoke from most prescribed fires can be assumed to be confined below this mixing height for smoke travel times up to 12 hours (Pharo and others 1976).

Pollutants within the mixing layer are directly diluted by the transport windspeed (the average windspeed within the mixing layer). Transport windspeed is generally regarded as having the most profound effect on pollutant concentrations. When multiplied by mixing height, transport windspeed yields ventilation factor.

The effect of transport windspeed or ventilation factor on atmospheric smoke concentrations can perhaps best be visualized by conceiving the atmosphere as a box into which pollutants are being poured. The height of the box is typically the mixing height. Consider smoke being emitted along the upwind edge of the box for a fixed period of time; e.g., 1 hour. During that period, the area downwind covered with smoke would depend on the windspeed within the box; for example, a 16-km per hour (10 mi/h) windspeed would make the box 48 km long in 1 hour. Half that windspeed results in a box of half the size and doubles the concentrations of smoke.

Ventilation factor has been used by the National Weather Service to help determine where stagnation episodes, associated with high pollution levels in urban areas, might occur.[1] It has utility particularly in considering pollutant buildup or dispersal for a day or more. Because dispersion rate within the conceptual "box" is neglected, ventilation factor does not describe the effect of individual pollution sources, nor the effect of all sources during portions of the day. Dispersion rate and the ventilation factor are considered in EPA dispersion models. One such model, the Climatological Dispersion Model (Busse and Zimmerman 1973), appears to lend itself to the construction of a dispersion index that may be able to indicate the amount of prescribed fire activity which can be accommodated in a 50- by 50-km area (approximately 1,000 mi^2 or roughly 30 by 30 mi) over a period of several hours.

Mathematical Basis of the Dispersion Index

The dispersion index that is proposed for prescribed fire smoke management is based primarily on the Climatological Dispersion Model (CDM) and ventilation factor. For the purpose of constructing the index, a slight modification to the CDM model is made to differentiate between typical dispersion conditions during day and night in rural terrain, according to the suggested dispersion rates given by Pasquill (1974). The dispersion index is optimized for application to burning activity within a 50- by 50-km area. It is constructed to reflect the amount of emissions within the area that will result in a fixed incremental increase of concentrations at the downwind edge of the area. (The

[1] National Weather Service Technical Procedures Bulletin 204, Air Stagnation Guidance. NOAA Tech. Dev. Lab., Silver Spring, MD. 10 pp.

downwind edge of a uniform area emission source with zero plume rise receives the greatest impact from such emissions.)

Ventilation Factor

The concentration of pollutants in the atmosphere at the downwind edge of a uniform area source shaped as a square, assuming complete mixing from ground to the mixing height (box model assumption) is

$$\chi = \frac{kQ}{LHW} \qquad (1)$$

where: χ = concentration due to emissions within the area
Q = total emission rate within the area
L = length of the area source
H = mixing height
W = transport windspeed
k = a constant, which reflects the units chosen for χ, Q, L, H, and W ($k = 1$, if any internally consistent set of units, e.g., SI units, are chosen)

Note that since the area is square, then

$Q = q_A L^2$ where q_A is the uniform area emission rate of the square.

Equation (1) neglects the concentration of pollutants that might be transported from an area farther upwind from the square area considered. A visual conception of equation (1) is shown in figure 1, but the effect of transport windspeed on the concentration χ is not shown. The windspeed effect is due to the concentration being a function of emission rate. The emissions which enter a block of air moving through the emission area are proportional to the amount of time required for the block to pass over the area, which is merely $L W^{-1}$, thus

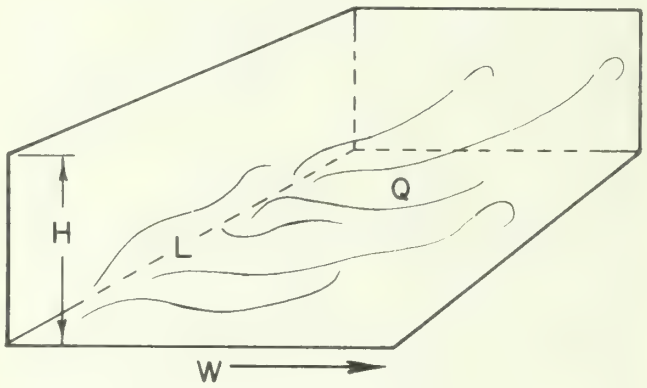
$$\chi = q_A L (HW)^{-1} \qquad (1A)$$

represents the concentration at the downwind edge of the box due to emissions within the box.

Now, let χ_{max} be some maximum allowable increment of pollutant concentration at the downwind edge of some square area due to burning activity within the area. The maximum acceptable emission rate for the area as a whole according to the box model is

$$Q_{max} = \frac{\chi_{max} LHW}{k} \qquad (2)$$

The quantity, HW, the product of mixing height and transport windspeed, is ventilation factor. If the box model perfectly reflected atmospheric dispersion rate, acceptable levels of burning activity, Q_{max}, would be proportional to ventilation factor.



Box model assumption: Smoke Q is emitted along line L, transported by wind W, and trapped within a box of depth H.

Figure 1.--Box model concept.

In general, the equation (2) model does not describe dispersion rate within the box. Typically, dispersion rates within the atmosphere are such that pollutants tend to approach uniform concentrations within the mixing layer. The rate of approach to uniformity, however, can be an important factor in determining ground-level concentrations. The rate of approach is a function of dispersion rate within the mixing layer when that rate is much greater than dispersion rate above the mixing height. The Gaussian dispersion model represents a frequently used method to account for the rate of dispersion within the mixing layer, as well as for many instances when the mixing height is effectively zero.

Gaussian Dispersion Modeling for Area Sources

Gaussian dispersion models (Turner 1970) are considered state of the art (EPA 1978) for modeling air-quality impact of individual sources for distances up to 50 km. More refined models are available, and sometimes necessary, but the Gaussian plume approach represents a compromise between cost, general applicability, known performance, and availability of efficient computerized algorithms. This approach has been used for sources of widely varying configurations, including individual prescribed fires (SFFLS 1976). For a uniform area source shaped as a square, emitting at ground level, the concentration at the downwind edge of the area according to the Gaussian dispersion model is:

$$\chi = q_A \int_0^L \frac{2}{\sqrt{2\pi}\,\sigma_z(x,H,S)\,W}\,dx \qquad (3)$$

where: $\sigma_z(x,H,S)$ is the vertical dispersion coefficient, a function of downwind distance, x, mixing height, H, and stability class, S.

...dx represents an integration with respect to downwind distance

π is 3.14159...

and it is assumed that the units of q_A, L, x, σ_z, H, and W are internally consistent (i.e., k = 1).

The stability class, S, in equation (3) does not represent a specific numerical quantity but refers to the classification system given in appendix A.

In steady-state Gaussian dispersion modeling, mixing height and wind are presumed to be constant in a given area for some period of time. Thus, under steady-state conditions, only σ_z needs to be integrated with respect to x.

The mathematical form of σ_z is:

$$\sigma_z = \text{minimum}\left(ax^b, \frac{2}{\sqrt{2\pi}}H\right) \qquad (4)$$

(but σ_z must not exceed 5,000 m)

where: a and b are constants within a stated range of x (a > 0, b > 0)

Note that if ax^b exceeds $\frac{2}{\sqrt{2\pi}}H$ within the range of distances x_{low} and x_{high}, the solution of the integral within equation (3) is:

$$\frac{x_{high} - x_{low}}{HW}$$

which is to say that if ax^b exceeds $\frac{2}{\sqrt{2\pi}}H$ over some range of distances, the box model is applicable for that range of distances:

$$\chi\,(x_{low} \text{ to } x_{high}) = \frac{q_A\,(x_{high} - x_{low})}{HW} \qquad (5)$$

where: $\chi\,(x_{low}$ to $x_{high})$ denotes concentration due to emissions within the portion of the area lying at distances x_{low} to x_{high} upwind of the downwind edge of the square area.

A "critical" distance, x_c can be defined in such a way that the following relationship is true:

$$\sigma_z = a\,x_c^{\,b} = \frac{2}{\sqrt{2\pi}}H \qquad (6)$$

if a and b are applicable at the distance x_c.

For a given mixing height and stability class, equations (3), (4), and (6) may be combined to yield

$$\chi = q_A \frac{2}{\sqrt{2\pi}\,W} \int_0^{A_M} \frac{1}{ax^b}\,dx + q_A \frac{L - A_M}{HW} \qquad (7)$$

where: A_M = minimum (L, x_c)

Values of a and b for each stability class are given in appendix C for ranges of downwind distance. For the most part, these are the same as those given by Busse and Zimmerman (1973). The values of a and b for near-neutral stability during daylight hours are modified to cause σ_z to be generally equivalent

to the recommendations of Pasquill (1974, p. 368, fig. 6.10). This modification of the CDM model was found to be necessary to produce a dispersion index that would not be unduly sensitive to small changes in weather variables used to estimate stability class.

Specification of Prescribed Fire Activity as an Area Source

Prescribed fires emit smoke into the atmosphere at varying heights according to the heat of the fires, windspeed, and properties of fire convection columns (such as entrainment of smoldering smoke). The specification of one or more plume heights as ranges of heights within a 2,500-km^2 area is necessarily arbitrary. To maintain relative mathematical simplicity, yet show the differing scopes of smoke impact due to fires with considerable plume rise versus smoldering smoke not associated with significant rise, the following assumptions are made:

Assumption 1. One-half of smoke emissions undergo extensive plume rises of varying heights in such a way that the aggregate effect is uniform mixing of smoke up to the mixing height.[2]

Assumption 2. One-half of smoke emissions undergo very limited plume rise with an aggregate effect being a ground-based Gaussian distribution of smoke with an initial value of 30 m (about 100 ft) for σ_z.

Assumption 1 requires no additional mathematical development. Assumption 2 may be accommodated through use of the EPA accepted "virtual distance" concept (Petersen 1978). This concept involves a "replacement" of the source, mathematically, at a distance, x_v, upwind of its actual location. Direct use of the Gaussian dispersion equations may be made with the x_v distance added to all downwind distances before computations are made. The value of x_v is dependent on initial (source configuration related) dispersion coefficient (30 m, according to Assumption 2) and stability class. Values of x_v are given in appendix C, table 3.[3]

To account for virtual distance, equation (7) is modified to:

$$\chi = q_A \frac{2}{\sqrt{2\pi}\, W} \int_{x_v}^{A_v} \frac{1}{ax^b}\, dx + q_A \frac{(L + x_v) - A_v}{HW} \quad (8)$$

where: A_v is minimum $(L + x_v, x_c)$.

Combining Assumptions 1 and 2 by use of equations (1A) and (8) leads to

$$\chi = \frac{0.5\, q_A L}{HW} + \frac{q_A}{\sqrt{2\pi}\, W} \int_{x_v}^{A_v} \frac{1}{ax^b}\, dx + 0.5\, q_A \frac{(L + x_v) - A_v}{HW} \quad (9)$$

The first and third terms in equation (9) can be combined but are kept separate to allow inspection of the separate effects of Assumptions 1 and 2. The quantity $\int_{x_v}^{A_v} \frac{1}{ax^b}\, dx$ may be integrated by the following means: Consider a and b within a given range of x as constants, then within that range of x, (x_{low} to x_{high})

$$\int_{x_{low}}^{x_{high}} \frac{1}{ax^b}\, dx = \frac{1}{a(1-b)} \left[x_{high}^{(1-b)} - x_{low}^{(1-b)} \right] \quad (10)$$

The results of the integration can be used as a term within a series within equation (9) as follows:

$$\chi = 0.5\, q_A \frac{L}{HW} + \frac{q_A}{\sqrt{2\pi}\, W} \sum_{i=1}^{3} \left[\frac{A_R^{(1-b_i)} - x_R^{(1-b_i)}}{a_i^{(1-b_i)}} \right] + 0.5\, q_A \frac{(L + x_v) - A_v}{HW} \quad (11)$$

where: A_R is minimum (x_{high}, A_v)
x_R is maximum (x_{low}, x_v)

and the series has three terms, since three ranges of x (three sets of x_{low} and x_{high}) are given in appendix C.

[2] If the atmosphere is stable (stability class 5, 6, or 7), mixing height is zero. During these conditions, the smoke emissions affected by plume rise are assumed to be uniformly mixed in a layer of depth, H_s. The method for obtaining H_s is given in appendix D, equation (38), derived from the box model equation (1).

[3] The CDM model does not consider virtual distance when utilizing an initial dispersion coefficient. The use of virtual distance allows the integral in equation (8) to be evaluated directly, saving computer space and time.

Note that both $x_R < A_v$ and $A_R > x_v$ must be true if the i^{th} term of the series in equation (9) is to be evaluated; if either condition is not met, the i^{th} term is zero.

Conversion of Concentration/Emissions Relationships to a Dispersion Index

The relationships among emission rate, weather parameters, and concentration given by equation (11) may be converted to a dispersion index by assigning a constant value to the area emission rate, q_A, solving for the concentration, X, then letting the reciprocal of concentration be the dispersion index. For the dispersion index considered here, let:

$$q_A = 0.002\ \mu g\ m^{-2} s^{-1} \tag{12}$$

$$L = 50{,}000\ m \tag{13}$$

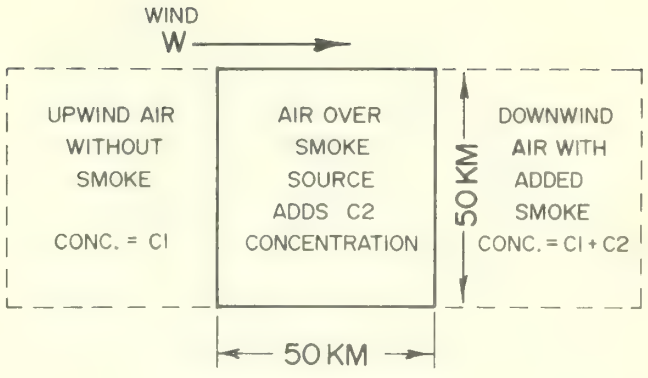
and the units of X be expressed in μg. Thus, the dispersion index determined from equations (11), (12), and (13) is:

$$\overline{DI} = \left(\frac{50}{HW} + \frac{0.002}{\sqrt{2\pi}\, W} \sum_{i=1}^{3} \left[\frac{A_R^{(1-b_i)} - x_R^{(1-b_i)}}{a_i^{(1-b_i)}} \right] + \frac{0.001\,(50{,}000 + x_V - A_V)}{HW} \right)^{-1} \tag{14}$$

where: $\overline{DI}$ signifies dispersion index in $m^2\ s^{-1}$.

The estimated concentration, along with the inversely proportional relationship between dispersion index and assumptions given by equations (12) and (13), implies that the dispersion index estimates the average (or total) emission rate within a square area that would result in a specific incremental increase of ground-level crosswind-averaged concentrations within a mass of air as it moves over the area (fig. 2).

The computer code in ANSI FORTRAN 77 language (Am. Natl. Stand. Inst. 1978) for determining the dispersion index, given stability class, daylight or dark, mixing height, and transport windspeed, is given in appendix E. The dispersion



$$C2 \cong \frac{(\text{constant}) \times (\text{emissions})}{(\text{dispersion index})}$$

or if C2 is restricted to a given value, the allowable emissions are: $Q \cong (\text{constant}) \times (\text{dispersion index})$

Figure 2.--Dispersion index concept (top view).

index of equation (14) may be thought of as being a 50:50 weighting of the index based on a ventilation factor:

$$\overline{DI_v} = \frac{HW}{100} \tag{15}$$

and a modified CDM model ground-level source-based dispersion index:

$$\overline{DI_c} = \left(\frac{0.004}{\sqrt{2\pi}\, W} \sum_{i=1}^{3} \left[\frac{A_R^{(1-b_i)} - x_R^{(1-b_i)}}{a_i^{(1-b_i)}} \right] + \frac{0.002\,(50{,}000 + x_V - A_V)}{HW} \right)^{-1} \tag{16}$$

The 50:50 weighting of equations (15) and (16), on a harmonic mean basis (see appendix B), is a direct result of Assumptions 1 and 2.

The relationship between any of the dispersion indices given by equations (14), (15), or (16) and maximum emission rate is:

$$Q_{max} = 5\chi_{max}\, \overline{DI'} \tag{17}$$

or

$$(q_A)_{max} = 0.002\chi_{max}\, \overline{DI'} \tag{18}$$

where: Q_{max} is maximum total emission rate (g s^{-1}) within the entire area

$(q_A)_{max}$ is maximum area-averaged emission rate (μg $m^{-2}s^{-1}$)

χ_{max} is maximum (acceptable) incremental increase in crosswind-averaged concentrations due to emissions within the area ($\mu g\ m^{-3}$)

and $\overline{DI'}$ is any of the dispersion indices, $\overline{DI}$, $\underline{\overline{DI}}_v$, or $\underline{\overline{DI}}_c$

Thus, the dispersion index can be used as an estimate of the level of prescribed fire activity that can be conducted in a given area without resulting in unacceptably high increases in smoke concentrations on an areawide basis.

None of the dispersion indices is a valid indicator for localized smoke management because the variation of concentrations due to fire locations within the area is not accounted for. A dispersion index could be constructed for an individual fire. However, since fires vary widely in size, energy release rate, convection column orientation, and distance to potential smoke-sensitive areas, no single indexing procedure would likely be applicable for more than a small fraction of all prescribed fires.

It must be stressed that steady-state (unchanging) weather conditions must prevail throughout the area where the dispersion index is being determined for equations (14)-(16) to be valid. Steady-state weather should be maintained, at minimum, for the length of time, Δt, required for smoke emitted at the upwind edge of the area to reach the downwind edge:

$$\Delta t \geq \frac{L}{W} = \frac{50{,}000}{W} \qquad (19)$$

where: the units of Δt are s, and W are $m\ s^{-1}$.

The mean value of transport windspeed in the 48 contiguous States is about $5\ m\ s^{-1}$ (Holzworth 1972), so the weather parameters used to determine dispersion index over the area should reflect conditions over at least a 3-hour period. If the index is to be used on a comparative basis for purposes of smoke management meteorology, a period of 6 hours should be considered so that the relative effect of weather during high versus low transport windspeed conditions can be directly compared with minimal error. Recommendations on use of the dispersion index are made in a later section.

Response of the Dispersion Index to Meteorological Parameters

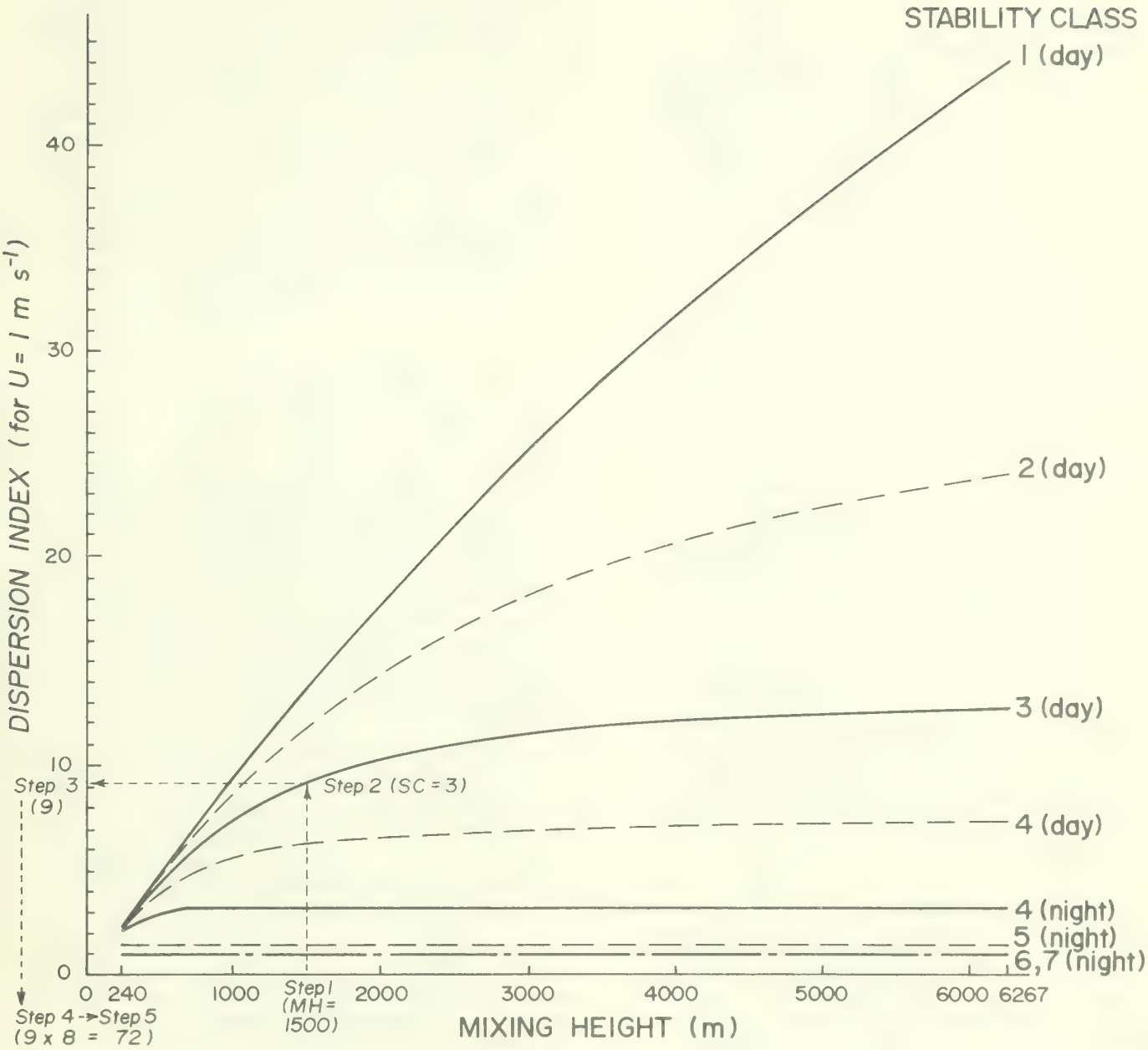
The dispersion index, $\overline{DI}$, given by equation (14) (accounting both for well-mixed and ground smoke), is directly proportional to transport windspeed. For example, with unchanged mixing height and stability class, doubling transport windspeed doubles the dispersion index. Doubling the mixing height will also increase dispersion index, but due to incomplete mixing within the mixing layer (see the summation term within equation (14)) the index may not double. Dispersion index also is increased when the stability class indicates a more unstable atmosphere (i.e., a lower class letter or number, according to the estimation method in appendix A). Figure 3 shows the response of dispersion index versus mixing height for each stability class, with transport windspeed set to the minimum recommended value (Turner and Novak 1978a, 1978b) of $1\ m\ s^{-1}$. Note that for the most unstable category, the response tends to be close to that expected from ventilation factor alone (equation (15)). This response results from the highly efficient mixing process attributed to a very unstable atmosphere by the CDM model algorithm. Certain restrictions on the value of mixing height, H, have been made in constructing figure 3 to reflect reasonable meteorological conditions:

$H = H_s \geq 240$ m (daytime; also nighttime when stability class is near neutral) (20)

$H = H_s \leq 600$ m (nighttime; near neutral stability only) (21)

$H_s = 180$ m (if stability class is slightly stable) (22)

$H_s = 150$ m (if stability class is moderately stable or very stable) (23)



STEPS FOR GRAPHICAL DETERMINATION OF DISPERSION INDEX:

1. Find mixing height along X axis (e.g., 1500 m)
2. Trace vertically until intercepting appropriate stability class (e.g., SC = 3)
3. Trace horizontally (to left) until intercepting Y axis (the U = 1 m s^{-1} dispersion index) (e.g., approx. 9)
4. Multiply Y axis value by the transport windspeed (in meters per second) (e.g., 9 x 8 m s^{-1})
5. Result is dispersion index (e.g., approx. 72)

Figure 3.--Response of dispersion index to mixing height, by stability class (transport windspeed = 1 m s^{-1}).

where: H_s in equations (20) to (23) is the depth of the smoke-burdened atmospheric layer, due to plume rise.

Equation (20) allows for the effect of plume rise from prescribed fires during neutral or unstable atmospheric conditions near the ground with some penetration or slow mixing into an overlying stable layer very near the ground. Equation (21) accounts for the at least slightly subadiabatic conditions usually observed near the ground at night, regardless of the indicated stability category (Lavdas 1981). Superadiabatic conditions resulting in nocturnal mixing heights calculated by the parcel method (Hess 1959) being significantly nonzero are a likely indicator of dangerous fire weather (Byram 1959). The 600-m restriction represents the estimated effective extent of mixing from a ground-level source in near-neutral conditions after 100 km of travel (Lavdas 1982; Turner 1970). Conditions as expressed by equations (22) and (23) represent values of H_s, not mixing height (which is zero), during stable conditions (classes 5, 6, and 7). These values of H_s take into account stable plume rise from Briggs (1972) due to point sources of sensible heat flux up to 1,000 $m^4\ s^{-3}$, as well as the effect of dispersion during downwind transport (see appendix D).

The curve labeled 4-DAY in figure 3 represents the only substantial alteration to models or modeling practices currently approved by the EPA. This curve corresponds to the D(1) stability category of Pasquill (1974, p. 368). The adaptation of this procedure removes the most serious of the dispersion index discontinuities, which are created by the use of stability classes rather than a continuous stability function. The mixing height (referred to by Pasquill as "the top of the dry-adiabatic layer") directly contributes to the value of the vertical dispersion coefficient, σ_z, in the D(1) stability class, although it does so for no other category. In the computation of dispersion index, the mixing height dependence of σ_z is accounted for in the calculation of the critical distance, x_c, beyond which uniform mixing is assumed by the CDM model. This uniform mixing assumption allows the 4-DAY stability values of σ_z to be calculated without explicitly considering mixing height. The constants a and b, given in appendix C, are the same as those given by Busse and Zimmerman (1973) except for the 4-DAY class. For the 4-DAY class, the CDM constants for less than 500 m are applied at all distances, which yield a linear curve on a log-log graph of σ_z versus x, as is shown by Pasquill.

Use of the Dispersion Index

The dispersion index offers a means of allocating prescribed fire emissions within an area, according to prevailing weather conditions, to avoid regional smoke overload. The index is based on the EPA-approved CDM model and constructed around the crosswind-averaged concentration impact at the downwind edge of a 50- by 50-km area (about 1,000 m^2) due to fire activity within the area. Smoke concentrations at specific locations are not accounted for; methods such as those given in SFFLS (1976) should be used to avoid overload due to individual fires. The dispersion index does not give a direct indication of the impact of smoke that travels in excess of 50 km. The likely effects of smoke upwind of the basic 50- by 50-km area should be considered before attempting a specific limitation on emissions based on a mandated value of X_{max}. Because of the assumptions used in constructing the index and the inherent limitations of the CDM model, it is suggested that the dispersion index be calibrated against prescribed fire activity in areas of similar fuel types and firing practices. The dispersion index is designed to have a one-to-one correspondence to the emissions from prescribed fire acceptable from an area-averaged, air-quality standpoint. A subjective interpretation of the dispersion index based on stagnation criteria, climatological values of ventilation and stability, and weather

conditions frequently sought for prescribed burning activity is given in table 1.

Table 1.--Preliminary interpretation of dispersion index values

Dispersion index	Interpretation
>100	Very good (but may indirectly indicate hazardous conditions; check fire weather)
61-100	Good (Southern Forest Fire Laboratory Staff 1976; typical-case burning weather values are in this range)
41-60	Generally good (climatological afternoon values in most inland forested areas of the United States fall in this range)
21-40	Fair (stagnation may be indicated if accompanied by persistent low windspeeds)
13-20	Generally poor; stagnation, if persistent (although better than average for a night value)
7-12	Poor; stagnant at day (but near or above average at night)
1-6	Very poor (very frequent at night; represents the majority of nights in many locations)

As already pointed out, the dispersion index should be based on weather conditions within the area that are representative over a 6-hour period. For example, a forecast of maximum surface temperature, expected afternoon cloud cover, and windspeeds combined with the projected upper-air conditions would generally yield values of mixing height, transport windspeed, and stability class that would be representative of conditions throughout the afternoon. If a dispersion index climatology is being constructed from hourly observations, it is suggested that it be calculated as the harmonic mean of six hour-by-hour "raw indices." The harmonic mean is suggested since the dispersion index corresponds to the reciprocal of concentration impact, and concentration impact is normally arithmetically averaged. Calculation of the harmonic mean is shown in appendix B.

When using surface and upper-air observations or forecasts to obtain mixing height, transport windspeed, and stability class over a 6-hour period of interest, keep the following points in mind:

1. Consider the variability of the atmospheric conditions (sun angle, cloud cover, ceiling, and windspeed) used to estimate stability class. Be sure a representative class is chosen, particularly if hour-by-hour computations are not made.

2. Consider the likely changes in mixing height, particularly the mixing that is likely to affect the smoke from both active and smoldering fires. The effective mixing height often drops rapidly to a low value around sunset as a surface-based nocturnal inversion forms. (The "parcel method," based on an early morning sounding, may give an anomalously high value for this purpose.) The restrictions on mixing height--conditions expressed by equations (20)-(23)--may be applicable. Consider the depth of atmosphere likely to contain smoke as being perhaps a more applicable estimate of mixing height than the definition given by strict thermodynamics considerations.

3. Consider the reliability of available data for the area of interest when evaluating the information. For instance, a nearby 1-hour-old surface-wind report should be given increased consideration when averaged against a more distant sounding that is several hours old. Smoke impact is often a ground-based phenomenon. Giving the

latest surface-wind observation 50 percent weight in determining the transport windspeed may be reasonable, particularly if the wind report is representative of the overall surface-wind pattern. In general, the surface windspeed report within the upper-air sounding should be disregarded unless that report is recent and representative.

Finally, it should be stressed that a burn/no burn decision for a given prescribed fire should not be based solely on the index. Dispersion index is not designed to account for the effect of high relative humidity on visibility in smoke. It is necessary for the prescribed burner to avoid smoke emissions during high-humidity periods, especially during poor-dispersion conditions. Also, no matter how good the dispersion index, it is possible for a fire to overload the atmosphere at nearby smoke-sensitive locations. The index is designed as an indicator of the atmosphere's capability to disperse pollutants on an areawide basis. It does not account for locally high smoke concentrations or the effects of smoke concentrations on visibility in high humidity.

List of Symbols

A_M - Minimum value of either the downwind length of the area source model, or x_c (m).

A_R - Minimum value of either the longest downwind distance for which the power law constants (a and b) are applicable, or the downwind length of the area source model plus virtual distance, or x_c (m).

A_V - Minimum value of either the downwind length of the area source model plus virtual distance, or x_c (m).

a - A value, which depends on stability class and is constant for a range of downwind distances, which is used in the power law expression, ax^b, to compute the vertical dispersion coefficient from downwind distance (dimensionless).

a_1 - Specific value of the constant, a, which is applicable for one of these ranges of downwind distances: 100-500 m, 500-5,000 m, > 5,000 m (dimensionless).

b - A value, dependent on stability class and constant for a range of downwind distances, used to compute the vertical dispersion coefficient (dimensionless) (see the definition of a).

b_1 - Specific value of the constant, b (dimensionless) (see definition of a_1).

$\underline{\overline{DI}}$ - Dispersion index, based both on ventilation factor and the concentration at the downwind edge of a uniform area source according to the Climatological Dispersion Model ($m^2\ s^{-1}$).

$\underline{\overline{DI}}_c$ - Dispersion index based solely on the concentration at the downwind edge of a uniform area source according to the Climatological Dispersion Model ($m^2\ s^{-1}$).

$\underline{\overline{DI}}_v$ - Dispersion index based solely on ventilation factor ($m^2\ s^{-1}$).

$\underline{\overline{DI}}'$ - Any of the three above dispersion indices ($m^2\ s^{-1}$).

exp(...) - Denotes exponentiation of the quantity in parentheses (no associated dimensions).

F - Sensible heat flux from some source, such as a prescribed burn ($m^4\ s^{-3}$).

g - Acceleration due to gravity ($m\ s^{-2}$).

H - Mixing height; the height at and below which atmospheric dispersion is rapid (may be zero at night) (m).

H_{MEAN} - The unweighted harmonic mean (units of individual entities that are calculated).

H_{MEANW} - The weighted harmonic mean (units as for H_{MEAN}).

H_S - Depth of a uniformly mixed ground-based smoke layer due to effects of both plume rise from fires and atmospheric dispersion (m).

Δh - Plume rise due to the heat of the fire (m).

k - A multiplicative units-dependent constant used when computing concentration in a box model ($k = 1$ in this study; often $k = 10^6$ to account for micrograms per gram) (dimensionless).

L - Downwind length of the area source model for computing concentrations (50,000 m in this study) (m).

n - Number of quantities considered in an averaging process (dimensionless).

$P(Z,\sigma_z^{-1})$ - Integral of the normal distribution, expressed in terms of the ratio of $(Z\sigma_z^{-1})$ dimensionless).

$\overline{P(Z,\sigma_z^{-1})}$ - The mean value of the above integral within a 50 x 50 km square area (dimensionless).

Q - The total emission rate of the area source (kg s^{-1}).

$(Q_H)_{Mcal}$ - Total sensible heat release rate from a prescribed fire (megacalories s^{-1}).

$(Q_H)_{MW}$ - Total sensible heat release rate (megawatts).

Q_{max} - Maximum acceptable emission rate of the area source (i.e., that which results in the maximum acceptable incremental increase of pollutant concentration at the downwind edge of the area) (kg s^{-1}).

Q_x - Emission rate from a vertical plane at some specific upwind distance, x, from a reference receptor; conversely, emission rate associated with relative concentration at some specific downwind distance, as derived in appendix D (kg s^{-1}).

Q_Z - Total emission rate from a line source at height, Z(kg s^{-1}).

q_A - The uniform area-averaged emission rate (kg m^{-2} s^{-1}).

$(q_A)_{max}$ - The maximum acceptable uniform area-averaged emission rate (analogous to Q_{max}) (kg m^{-2} s^{-1}).

S - The Pasquill-Gifford-Turner stability class, expressed as a number from 1 to 7 (dimensionless).

Δt - Length of time required for emissions at the upwind edge of the area source to be transported to the downwind edge of the area (s).

W - Transport windspeed, the average windspeed in the mixing layer (if atmospheric stability is unstable or neutral), or in the portion of a surface-based stable layer containing significant amount of pollutants (if the atmospheric stability is stable) (m s^{-1}).

W_h - Representative windspeed within the layer of atmosphere through which plume rise occurs (m).

wf - Weighting factor in an averaging process (dimensionless).

x - Downwind distance from the real or virtual origin of emissions from a point or line source (m).

x_c - Critical downwind distance, x, at which vertical Gaussian dispersion from a ground-based source is equivalent to vertically uniform dispersion trapped between the ground and the mixing height, H (m). (If the atmospheric stability is stable, x_c is regarded as being much larger than 50,000 m.)

x_{high} - Longest downwind distance for which specific values of the power law coefficients (a_1, b_1) are applicable (m).

x_{low} - Shortest downwind distance for which specific values of the power law coefficients (a_1, b_1) are applicable (m).

x_r - Maximum of x_{low} (associated with specific values of a_1 and b_1), or the virtual downwind distance, x_v (m).

x_v - Virtual downwind distance increment; a nonpoint source, which has a characteristic initial Gaussian distribution at the source origin (a vertical dispersion coefficient of 30 m is assumed in this study), has a concentration pattern (in steady-state uniform Gaussian dispersion modeling) identical to a "fictitious" point source at a location upwind of the actual nonpoint source. The distance from the fictitious point source to the actual source location is the virtual downwind distance (m).

y - A general quantity that is being averaged (see appendix B).

Z - Height above the ground of a smoke-emissions source (m).

θ - Potential temperature; i.e., that temperature an atmospheric parcel would have if its pressure changed to 1,000 millibars with no heating, using an ideal gas assumption (K).

$\frac{\delta\theta}{\delta Z}$ - Change of potential temperature with respect to height ($K\ m^{-1}$).

π - 3.14159. . . (dimensionless).

χ - Concentrations due to the emissions of a specific source or set of sources (e.g., all sources within an area, or a uniform area source) ($kg\ m^{-3}$).

χ_L - Concentration due to a line source ($kg\ m^{-3}$).

χ_{max} - Maximum acceptable increment of concentration that can be tolerated due to the emissions of a specific source or set of sources ($kg\ m^{-3}$).

χ_x - Concentration from a vertical plane at some specific upwind distance, x; conversely, concentration associated with relative concentration at some specific downwind distance, as derived in appendix D ($kg\ m^{-3}$). (Note: The general form of relative concentration is ($\chi\ Q\ W^{-1}$), with units of (m^{-2}).)

σ_z - The Gaussian vertical dispersion coefficient (m).

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APPENDIXES

APPENDIX A

Stability Class Estimation Method

Input data required to determine stability class[4] include solar elevation angle in degrees, total opaque cloud cover in tenths, ceiling height in feet, and surface windspeed in knots. If ceiling is undefined due to little or no cloudiness, it should be regarded as >99,000 ft; if ceiling is undefined due to surface-based obscuration, consider the sky as totally covered with opaque clouds, and the vertical visibility may be used in place of ceiling height. The other parameters are defined in the same way as in National Weather Service operations (for example, surface windspeed is the windspeed 20 ft above open terrain).

The stability class is determined through an estimate of net radiation and surface windspeed. A net radiation index is obtained by the following procedure:

I. If the total opaque cloud cover is 10/10 and the ceiling height is <7,000 ft, use net radiation index equal to 0 (whether day or night).

II. For nighttime (between sunset and sunrise):

   A. If total opaque cloud cover ≤4/10, use net radiation index equal to -2.

   B. If total opaque cloud cover >4/10, use net radiation index equal to -1. (Note that this will not apply for cases of 10/10 coverage when ceiling <7,000 ft, since such cases are determined by step I, above).

III. For daytime:

   A. Determine the insolation class number as a function of solar elevation angle according to the following:

Solar elevation angle (δ)	Insolation class number
$60° < \delta$	4
$35° < \delta \leq 60°$	3
$15° < \delta \leq 35°$	2
$\delta \leq 15°$	1

   B. If the total opaque cloud cover ≤5/10, the net radiation index is equal to the insolation class number.

   C. If the total opaque cloud cover >5/10, modify the insolation class number by following these six steps:

      1. Ceiling height less than 7,000 ft, subtract 2.

      2. Ceiling height greater than or equal to 7,000 ft but less than 16,000 ft, subtract 1.

      3. Total opaque cloud cover equal 10/10, subtract 1. (This will only apply to ceilings greater than or equal to 7,000 ft because cases with 10/10 coverage with ceiling less than 7,000 ft are determined by step I, above.)

      4. If neither steps 1 and 2 nor 3 immediately above are applicable, assume that the modified insolation class number is equal to the insolation class number.

      5. If the modified insolation class number is less than 1, let it equal 1.

      6. Set the net radiation index equal to the modified insolation class number.

The stability class is estimated as a function of net radiation index and surface windspeed according to table 2.

[4]The method in this appendix is the same as that used in Turner (1961, 1964).

The numerical value of stability class given in table 2 may be interpreted in the following manner:

Stability class	Interpretation
1 (or Pasquill A)	Very unstable
2 (or Pasquill B)	Moderately unstable
3 (or Pasquill C)	Slightly unstable
4 (or Pasquill D)	Near neutral
5 (or Pasquill E)	Slightly stable
6 (or Pasquill F)	Moderately stable
7 (or Pasquill _, sometimes G)	Very stable

When used in determining dispersion index from hour-by-hour surface weather observations, the stability class should not be allowed to vary by more than one class per hour. This restriction is imposed to help account for the effects of changing weather conditions on concentrations due to pollutants undergoing transport for several hours.

The system is the same as that used in most EPA atmospheric dispersion models. Occasionally, a given model may redefine certain stability classes to account for urban heating effects on a stable atmosphere. Such adjustments are not used in formulating a dispersion index because prescribed burning is a rural phenomenon; even its impact on the upwind edge of an urban area will reflect predominantly rural dispersion conditions. One adjustment is made for the near-neutral class 4--subclasses 4-DAY and 4-NIGHT are defined where 4-DAY refers to stability class 4 with the solar elevation angle above the horizon, and 4-NIGHT is applicable to the period from sunset to sunrise.

Table 2.--Stability class as a function of net radiation index and surface windspeed

Windspeed (knots)	Net radiation index						
	4	3	2	1	0	-1	-2
0-1	1	1	2	3	4	6	7
2	1	2	2	3	4	6	7
3	1	2	2	3	4	6	7
4	1	2	3	4	4	5	6
5	1	2	3	4	4	5	6
6	2	2	3	4	4	5	6
7	2	2	3	4	4	4	5
8	2	3	3	4	4	4	5
9	2	3	3	4	4	4	5
10	3	3	4	4	4	4	5
11	3	3	4	4	4	4	4
≥12	3	4	4	4	4	4	4

APPENDIX B

Calculating the Unweighted or Weighted Harmonic Mean

The unweighted (simple) harmonic mean, H_{MEAN}, of n values of y is

$$H_{MEAN} = \frac{n}{\sum_{i=1}^{n}\left(\frac{1}{y_i}\right)} \tag{24}$$

where y_i denotes an individual value of y.

For example, the simple harmonic mean of {4, 5, 10, 40, 50, 200} is

$$H_{MEAN} = \frac{6}{\left(\frac{1}{4}+\frac{1}{5}+\frac{1}{10}+\frac{1}{40}+\frac{1}{50}+\frac{1}{200}\right)} = \frac{6}{0.6} \tag{25}$$

or $H_{MEAN} = 10$

where the dimensions of H_{MEAN} are the same as for each and every individual value of y_i.

The weighted harmonic mean, H_{MEANW}, is calculated in an analogous manner. In this case, n is replaced by the sum of the individual weighting factors wf_i, associated with individual values of y_i, that is:

$$H_{MEANW} = \frac{\sum_{i=1}^{n}(wf_i)}{\sum_{i=1}^{n}\frac{(wf_i)}{(y_i)}} \tag{26}$$

For example, if there are three numbers {3, 5, 9} where 3 and 5 have weighting factors of 2, and 9 has a weighting factor of 3, then

$$H_{MEANW} = \frac{(2 \times 2 \times 3)}{\left(\frac{2}{3}+\frac{2}{5}+\frac{3}{9}\right)} = \frac{7}{\left(\frac{7}{5}\right)} \tag{27}$$

or $H_{MEANW} = 5$

Note that this result is identical to the simple harmonic mean of seven numbers {3, 3, 5, 5, 9, 9, 9} or

$$H_{MEAN} = \frac{7}{\left(\frac{1}{3}+\frac{1}{3}+\frac{1}{5}+\frac{1}{5}+\frac{1}{9}+\frac{1}{9}+\frac{1}{9}\right)} = 5 \tag{28}$$

APPENDIX C

Effect of Stability Class and Downwind Distance on the Vertical Gaussian Dispersion Coefficient σ_z, Critical Distance x_c, and Virtual Distance Increment x_v

The vertical Gaussian dispersion coefficient, σ_z, is computed by use of the formula

$$\sigma_z = ax^b$$

given that

$$ax^b \leq \frac{2}{\sqrt{2\pi}} H \qquad (29)$$

otherwise

$$\sigma_z = \frac{2}{\sqrt{2\pi}} H \qquad (30)$$

where: σ_z is in meters

x is downwind distance, in meters, from a point source

a,b are constants, given a stability class and a specific range of x

and H is mixing height in meters.

The virtual distance, x_v, is defined in a manner somewhat similar to x_c; that is, x_v is the value of x_y that satisfies the following equation

$$30 = a x_v^b \qquad (31)$$

where: a and b must be applicable for the specific value of x_v

and 30 is the assumed initial value of σ_z, in meters (this is analogous to the process performed in equation (6)).

Table 3 gives the values of the parameters a, b, and x_v as a function of stability class (and, in the case of a and b, downwind distance x). Note that x_v may be found from a knowledge of stability class only, while mixing height, H, and downwind distance, x, must also be available to determine σ_z.

Table 3.--Values of parameters a, b, and x_v as a function of stability class and downwind distance

Stability class	100 m < x < 500 m		500 m < x < 5,000 m		x > 5,000 m		x_v
	a	b	a	b	a	b	(30 m)
1	0.0383	1.2812	0.0002539	2.0886	0.0002539	2.0886	181.46
2	0.1393	0.9467	0.04936	1.1137	0.04936	1.1137	291.43
3	0.1120	0.9100	0.1014	0.9260	0.1154	0.9109	465.62
4-DAY	0.0856	0.8650	0.0856	0.8650	0.0856	0.8650	874.56
4-NIGHT	0.0856	0.8650	0.2591	0.6869	0.7368	0.5642	1010.0
5	0.0818	0.8155	0.2527	0.6341	1.2969	0.4421	1869.0
6 and 7	0.0545	0.8124	0.2017	0.6020	1.5763	0.3606	4061.3

Note: x_v depends on stability class only.

To obtain a value of σ_z, find a and b in table 3, then use equations (29) and (30) as appropriate. Equation (29) applies at all distances, x, less than the critical downwind distance, x_c. Equation (30) applies for distances greater than x_c. The critical distance, x_c, is defined by equation (6); when rearranged, this equation is:

$$x_c = \left[\frac{\sqrt{2\pi}\, H}{2a}\right]^{1/b} \qquad (32)$$

where: a and b are the values from table 3 appropriate at distance x_c.

In most cases, the values of a and b for $x \geq 5{,}000$ m may be used in equation (32) to solve for x_c. This is because x_c is frequently greater than 5,000 m, particularly when the stability class is 4 or greater. For stability classes 1 and 2, x_c is often between 500 and 5,000 m, but the values for a and b are the same for all $x > 500$ m. For stability class 3, x_c is less than 5,000 m when mixing height, H, is less than 338.5 m. When the stability class is 5, 6, or 7, it is not necessary to determine x_c since mixing height is not defined for a stable atmosphere (in effect, the critical distance, x_c, is >50,000 m). Thus, to find x_c, follow either of these two steps:

1. If stability class is 1, 2, 3, 4-DAY, or 4-NIGHT

   a. If stability class is 3 and mixing height is <338.5 m, find a and b in table 3 for the $500 \text{ m} \leq x < 5{,}000$ m case, then solve equation (32) for x_c.

   b. If stability class is 3 and mixing height is ≥338.5, or stability class is 1, 2, 4-DAY, or 4-NIGHT, find a and b in table 3 for the $x \geq 5{,}000$ m case, then solve equation (32) for x_c.

2. If stability class is 5, 6, or 7, then x_c is in excess of (50,000 m + x_v); i.e., equation (30) is never used to find σ_z.

APPENDIX D

Depth of Prescribed Fire Smoke Layer in a Stable Atmosphere

The presence of smoke at a given height in the atmosphere over flat terrain (small ambient vertical velocity is assumed) is due to either the heat from a prescribed fire or an atmospheric dispersion process. In an unstable or nearly neutral atmosphere, the dispersion rate is sufficiently great to allow (for indexing purposes) the assumption of uniform mixing below the mixing height, H, for smoke associated with significant plume rise. This assumption fails in stable conditions; there is no thermally induced mixing height present. Thus, plume rise and dispersion processes are explicitly considered in determining the vertical disposition of smoke for stability classes 5, 6, 7.

According to Briggs (1972), plume rise from a point source in stable conditions may be determined from

$$\Delta h = 2.4 \left(\frac{F}{W_h \frac{g}{\theta} \frac{\delta\theta}{\delta Z}} \right)^{1/3} \qquad (33)$$

where: Δh is plume rise, in meters

F is sensible heat flux from the source ($m^4\ s^{-3}$)

g is acceleration of gravity ($m\ s^{-2}$)

W_h is representative windspeed within the plume rise layer ($m\ s^{-1}$),

θ is potential temperature (K)

and $\frac{\delta\theta}{\delta Z}$ is the change of potential temperature with respect to height ($K\ m^{-1}$).

Since plume rise in stable conditions (cube root dependency) is somewhat insensitive to the various independent variables in equation (33), it is possible to use representative variables of W_h for each stability class for determining a dispersion index. The U.S. Standard Atmosphere values for g and θ at sea level are 9.80665 $m\ s^{-2}$ and 287.1 K, respectively. In addition, Turner and Novak (1978b) use 0.020 $K\ m^{-1}$ (stability class 5) and 0.035 $K\ m^{-1}$ (stability class 6) for $\delta\theta/\delta Z$. The value of 0.035 $K\ m^{-1}$ is assumed to apply for stability class 7 as well, based on Lavdas (1981), who found that the Turner and Novak values were in excellent agreement with mean 0400 l.s.t. National Weather Service soundings for classes 5 and 6, and that the class 7 sounding was indistinguishable from class 6.

Surface windspeeds (in knots) associated with the various stability classes are shown in appendix A, table 2. For substantial values of Δh, W_h is in excess of the surface speed. Therefore, representative values of W_h are chosen to be 6.0 $m\ s^{-1}$ for stability class 5 and 3.5 $m\ s^{-1}$ for classes 6 and 7. The possibility of substantial variation of W_h from the above values in given cases would be important for most emission sources. It may be less important for actively burning prescribed fires because the rate of spread and intensity of a fire, hence F, increase with increasing windspeed (Rothermel 1972).

Sensible heat flux, F, varies widely among prescribed fires and during the life cycle of individual fires. The most intense fires generate enough heat to penetrate a typical nocturnal inversion during part of the life cycle. Such fires, however, represent a high enough potential smoke source to warrant the use of single-fire smoke management tools (SFFLS 1976) which are outside the scope of this paper. To determine F from low- to moderate-intensity prescribed fires, note that, according to Briggs (1975)

$$F \cong 8.9\,(Q_H)_{MW} \cong 37\,(Q_H)_{Mcal} \qquad (34)$$

where: $(Q_H)_{MW}$ is total sensible heat release rate in megawatts

and $(Q_H)_{Mcal}$ is the corresponding quantity in megacalories per second.

Values of $(Q_H)_{Mcal}$ from typical prescribed fires (SFFLS 1976) for actively burning nondebris fires range from about 5 to 140 Mcal s^{-1}. The median value of 26 Mcal s^{-1} is used with equation (34) to choose a representative value of 1,000 m^4 s^{-3} for F (applicable for stability classes 5, 6, and 7).

Substituting the various representative values into equation (33), one finds that

$$\Delta h \cong 150 \text{ m} \qquad (35)$$

for stability classes 5, 6, and 7. Because this value represents the highest plume rise from a prescribed fire during its life cycle, and due to substantial unentrained or partially entrained smoke with respect to the convection column in many prescribed fires, the prescribed fire smoke source associated with actively burning fires is specified as uniformly mixed from the ground to 150 m.

It is now necessary to consider the effect of vertical dispersion during downwind transport on such a source. Consider the concentration impact at the downwind edge of the 50- x 50-km area as shown in figure 4. Note that it is possible to calculate this impact by the alternative method of averaging the concentration along the ground-level center line from 0 to 50 km downwind from a vertical plane that extends from 0 to 150 m above the upwind boundary of the square area. The smoke concentration from a vertical plane may be obtained from integrating the effect of horizontal line sources along the plane. The equation for an essentially infinite line source, after Turner (1970), is

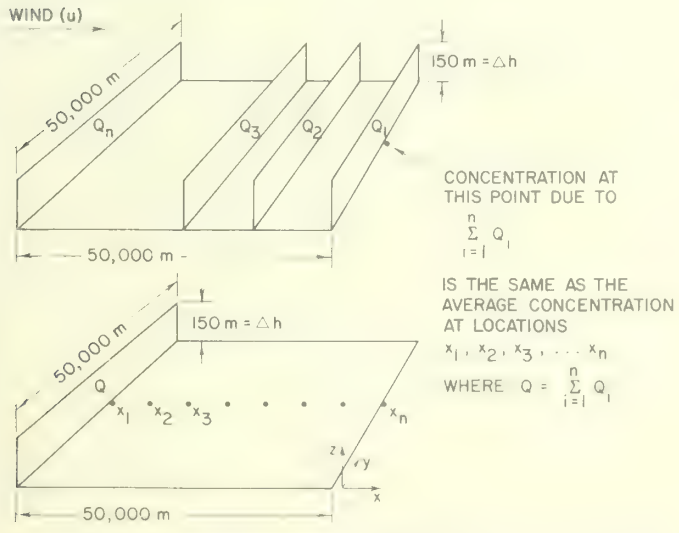

Figure 4.--Alternative methodologies for calculating concentrations from a series of vertical planes oriented perpendicular to the wind.

$$\chi_L = (2/\pi)^{1/2} W^{-1} \sigma_z^{-1} (Q_z/L) \exp(-0.5\, Z^2/\sigma_z^2) \qquad (36)$$

where:

χ_L is concentration at the ground from a line source at height Z (kg s^{-1})

Q_Z is total emission rate at height Z (kg s^{-1})

Z is height of source above the ground (m)

L is length of the area source

W is transport speed

σ_z is the Gaussian vertical dispersion coefficient (m).

To integrate equation (36) with respect to height, note that σ_z and χ_L are differential quantities. It is convenient to express equation (36) in terms of relative concentration and integrate from Z = 0 to Δh with respect to the ratio $(Z\sigma_z^{-1})$ obtaining an equation for relative concentration at a specific distance x

$$(\chi W Q^{-1})_x = (2L^{-1}\Delta h^{-1}) \int_{(0)}^{(\Delta h \sigma_z^{-1})} (2\pi)^{-1/2} \exp[-0.5\, Z^2/\sigma_z^2]\, d(Z\sigma_z^{-1}) \qquad (37)$$

where:

$(\chi W Q^{-1})_x$ is relative concentration at some downwind distance x(m^{-2})

(0) and $(\Delta h \sigma_z^{-1})$ are the limits of integration with respect to $d(Z\sigma_z^{-1})$

and the integral as a whole is henceforth referred to as $P(Z,\sigma_z^{-1})$.

Note that $P(Z,\sigma_z^{-1})$ is simply the integral of the normal distribution function with respect to the ratio $(Z\sigma_z^{-1})$. There are numerous tables and analytical approximations for obtaining this integral. Values for a few values of downwind distance are given in table 4.

Before determining the average relative concentration in the range from 0 to 50,000 m, it is useful to consider the relative concentration predicted by a simple box model with a uniform height, H_s. From equation (1),

$$\chi WQ^{-1} = (LH_s)^{-1} \quad (38)$$

Using equations (37) and (38), one finds a relationship for the depth of a uniform smoke layer, H_s, that would yield the same ground-level concentration as that experienced at a specific downwind distance from a source like that shown in figure 4.

$$(\Delta h/H_s)_x = 2P(Z,\sigma_z^{-1}) \quad (39)$$

where: $(\Delta h/H_s)_x$ denotes the ratio between Δh and H_s applicable at a specific distance, x.

To obtain the value of H_S applicable for the entire 50- x 50-km area, it is only necessary to determine the mean value of $P(Z,\sigma_z^{-1})$ over the range from 0 to 50,000 m; i.e., $\overline{P(Z,\sigma_z^{-1})}$. Because $(\Delta h\sigma_z^{-1})$ decreases with increasing x, $\overline{P(Z,\sigma_z^{-1})}$ is a continuously decreasing function with respect to x.

To calculate $\overline{P(Z,\sigma_z^{-1})}$ with arbitrary accuracy, one may compute the average of several values of $P(Z,\sigma_z^{-1})$ that are known to form upper and lower bounds for given intervals of x. For example, for values of x, between 15,000 and 17,500, $P(Z,\sigma_z^{-1})$ for stability class 5 is between 0.450 and 0.438. Using table 4 in this way (taking the average of all upper and lower bounds of $P(Z,\sigma_z^{-1})$ over intervals of 2,500), one can establish that:

$$0.40905 \leq \overline{P(Z,\sigma_z^{-1})} \leq 0.41740 \text{ (stability class 5)} \quad (40)$$

$$0.49020 \leq \overline{P(Z,\sigma_z^{-1})} \leq 0.49155 \text{ (stability class 6 or 7)} \quad (41)$$

Thus, from equations (35) and (39),

$$H_s \cong 180 \text{ m (stability class 5)} \quad (42)$$

$$H_s \cong 150 \text{ m (stability class 6 or 7)} \quad (43)$$

which are the same as equations (22) and (23) in the main text.

Table 4.--Upper limit of integration ($\Delta h\, \sigma_z^{-1}$) and probability integral $P(Z,\sigma_z^{-1})$ for various downwind distances, x, in stable conditions

	Stability Class 5		Stability Classes 6 and 7	
x(m)	($\Delta h\, \sigma_z^{-1}$)	$P(Z,\sigma_z^{-1})$	($\Delta h\, \sigma_z^{-1}$)	$P(Z,\sigma_z^{-1})$
0	∞	0.500	∞	0.500
2,500	4.16	.500	6.70	.500
5,000	2.68	.496	4.41	.500
7,500	2.24	.487	3.81	.500
10,000	1.97	.476	3.44	.500
12,500	1.79	.463	3.17	.499
15,000	1.65	.450	2.97	.499
17,500	1.54	.438	2.81	.498
20,000	1.45	.427	2.68	.496
22,500	1.38	.416	2.56	.495
25,000	1.31	.406	2.47	.493
27,500	1.26	.396	2.39	.491
30,000	1.21	.387	2.31	.490
32,500	1.17	.379	2.25	.488
35,000	1.13	.371	2.19	.486
37,500	1.10	.364	2.13	.484
40,000	1.07	.357	2.08	.481
42,500	1.04	.351	2.04	.479
45,000	1.01	.345	2.00	.477
47,500	0.99	.339	1.96	.475
50,000	0.97	.333	1.92	.473

The lower bound of integration is zero for all cases, Δh is 150 m, σ_z is found by use of table 3 in appendix C, $P(Z,\sigma_z^{-1})$ is calculated from equation 26.2.17 of Abramowitz and Stegun (1965).

APPENDIX E

A FORTRAN 77 Subroutine Package for Computing Dispersion Index for a Specific Time

The following subroutine package, consisting of one subroutine and two functions, provides a means for automated computation of dispersion index. The package is written in the widely used FORTRAN 77 language, and conforms to ANSI X3.9-1978, American National Standards Institute (1978). The package is invoked by using a FORTRAN CALL statement like the following:

```
CALL DSPNHR (IDYNT, ISTAB, AMIX, U,
             DINDHR)
```

where IDYNT is an integer, IDYNT should be set to 1 if dispersion index is being calculated during daylight hours (just after sunrise to just before sunset), otherwise IDYNT should be set to 2 (sunset to sunrise)

ISTAB is an integer from 1 to 7, representing stability class (see appendix A)

AMIX is a nonnegative real, representing mixing height in meters

U is a nonnegative real, representing transport windspeed in meters per second

and DINDHR is a real variable, which will contain the value of dispersion index, $\overline{DI}$.

Please note that in case of erroneous input, the subroutine package will output an error message to unit 6 and stop the execution of the calling program. If this action is unsatisfactory for a given application, the user should modify lines 00002500 through 00004300 of SUBROUTINE DSPNHR. However, some equivalent error checking should be performed to avoid a program crash.

When executing properly, the subroutine package will provide values of DINDHR as shown in table 5.

Table 5.--Example runs of FORTRAN subroutine package to determine dispersion index, DINDHR

Input				Correct output
IDYNT	ISTAB	AMIX	U	DINDHR
1	1	120.	0.5	2.382
1	1	120.	1.	2.382
1	1	240.	1.	2.382
1	1	240.	2.	4.764
1	1	1200.	1.	11.259
1	1	5000.	1.	37.663
1	1	8000.	1.	44.208
1	2	240.	1.	2.358
1	2	1200.	1.	9.983
1	2	5000.	1.	22.479
1	3	240.	1.	2.320
1	3	1200.	1.	8.263
1	3	5000.	1.	12.487
1	4	240.	1.	2.237
1	4	600.	1.	4.435
1	4	1200.	1.	5.965
1	4	5000.	1.	7.358
2	4	240.	1.	2.093
2	4	600.	1.	3.152
2	4	1200.	1.	3.152
2	5	240.	1.	1.471
2	5	600.	1.	1.471
2	6	240	1.	0.986
2	6	600.	1.	0.986
2	7	240.	1.	0.986

In utilizing this subroutine package, the user should be careful to input values of IDYNT, ISTAB, AMIX, and U, which are representative for the period of interest. One possibility for certain kinds of analyses would be to invoke the subroutine package for 3 to 6 successive hours, then compute the harmonic mean of the corresponding values

of DINDHR. For operational applications, it is better to pick representative input values during a period when atmospheric conditions are relatively constant. For example, two estimates of dispersion index, one for the last 6 hours before sunrise and the other for the period from near noon to just before sunset, should provide operationally useful information to those responsible for prescribed burning and air-quality protection over areas of about 1,000 square miles.

Copies of the dispersion index program, with a more comprehensive test program and documentation of the subroutine package structure, are available from the author.

Definitions of Variables

ACOEFF - A 3 by 6 array of constants, according to downwind distance and stability class, used in the power law A * X ** B to obtain vertical dispersion coefficient.

AMIX - Mixing height (global variable).

AMIXT - Temporary local value of mixing height.

AMXMAX - Maximum possible temporary mixing height value, associated with a vertical dispersion coefficient of 5,000 m.

BCOEFF - A 3 by 6 array of constants (as in ACOEFF).

BPOWER - Exponent of the mathematical expression obtained when integrating the reciprocal of A * X ** B with respect to X.

CONUAR - Sum of concentrations due to the area source for the range of downwind distances considered.

CON1 - Concentration due to a given range of downwind distances, all of which lie at a distance greater than the critical distance XCRIT.

CON2 - Concentration due to a given range of downwind distances, all of which lie at a distance less than the critical distance, XCRIT.

CRITGT - Function and variable that correspond to CON1, if CON1 >0.

CRITLT - Function and variable that correspond to CON2, if CON2 >0.

DINDHR - Dispersion index due to steady-state weather conditions for a given hour (global variable).

DPSMOK - Depth of the smoke layer in stable atmosphere, determined from AMIXT for stability classes 1-4, or by use of appendix D for the remaining classes.

I - A do-loop index variable used to calculate the sum of concentrations from emissions within three specific ranges of downwind distances: 100-500 m, 500-5,000 m, and >5,000 m.

ICOEFF - Indexing variable used to select the appropriate value for downwind distance range of ACOEFF and BCOEFF.

IDYNT - Indicator for daylight versus night hours: = 1 if day, = 2 if night (global variable).

ISTAB - The Turner (1964) stability class from 1 to 7 (global variable).

ISTABT - Temporary local value of Turner stability class.

PRTOFT - Constant term resulting from the integration of the reciprocal of the power law relationship with respect to downwind distance, X (BPOWER is also a result of this integration).

QA - Uniform area source emission rate for use in the CMD portion of the code only (i.e., one-half the value given in equation (12)).

TINTGL - Complete result of integrating the reciprocal of the power law relationship with respect to downwind distance, X, a function of BPOWER, PRTOFT, and the range of X considered. (This range is always less than XCRIT.)

U - Transport windspeed or, if a surface-based inversion is indicated, the average windspeed in the smoke-laden surface layer of atmosphere (global variable).

UT - Temporary local value of transport windspeed.

XCRIT - Critical downwind distance at and beyond which the vertical dispersion coefficient may be regarded as constant for the purposes of computing ground-level concentration from a ground-based source.

XHIGH - Longest downwind distance considered in a given area source concentration calculation.

XLIMIT - Array of four downwind distances that are used to define the range of distances for a given concentration calculation.

XLOW - Shortest downwind distance considered in a given area source concentration calculation.

XMAXGT - Value of XHIGH when performing a concentration calculation at distances greater than XCRIT.

XMAXLT - Value of XHIGH when performing a concentration calculation at distances less than XCRIT; XMAXLT may not exceed XCRIT.

XMINGT - Value of XLOW when performing a concentration calculation at distances greater than XCRIT; XMINGT may not be less than XCRIT.

XMINLT - Value of XLOW when performing a concentration calculation at distances less than XCRIT.

XMINST - Array of seven values of virtual distance with respect to stability class and day-night factor.

XMIN30 - Virtual downwind distance associated with a source with a vertical dispersion coefficient of 30 m, according to the indicated stability class and day-night factor.

Source Code Listing for Dispersion Index Subroutine Package

```
C***                                                                    00000100
C***HOURLY DISPERSION INDEX CALCULATION ROUTINE                         00000200
C***                                                                    00000300
      SUBROUTINE DSPNHR(IDYNT,ISTAB,AMIX,U,DINDHR)                      00000400
C***RESTRICTIONS ON INPUT VALUES:                                       00000500
C***  IDYNT MUST BE 1 OR 2                                              00000600
C***  ISTAB MUST BE 1, 2, 3, 4, 5, 6, OR 7                              00000700
C***  AMIX  MUST NOT BE NEGATIVE                                        00000800
C***  U     MUST NOT BE NEGATIVE                                        00000900
C***OUTPUT IS:  DINDHR, A POSITIVE REAL NUMBER                          00001000
      LOGICAL ERRFLG                                                    00001100
      DIMENSION ACOEFF(3,6),BCOEFF(3,6),XLIMIT(4),XMINST(7)             00001200
C***INITIALIZE ARRAYS AND AREA EMISSION RATE                            00001300
C***CDM VALUES USED FOR ACOEFF, BCOEFF, AND XLIMIT                      00001400
      DATA ACOEFF /.0383,.0002539,.0002539,.1393,.04936,.04936,         00001500
     & .1120,.1014,.1154,.0856,.2591,.7368,.0818,.2527,1.2969,          00001600
     & .0545,.2017,1.5763/                                              00001700
      DATA BCOEFF /1.2812,2.0886,2.0886,.9467,1.1137,1.1137,            00001800
     & .9100,.9260,.9109,.8650,.6869,.5642,.8155,.6341,.4421,           00001900
     & .8124,.6020,.3606/                                               00002000
      DATA XLIMIT /100.,500.,5000.,50000./                              00002100
C***XMINST VALUES ARE VIRTUAL DISTANCE UNDER SPECIFIED CONDITIONS       00002200
      DATA XMINST /181.46,291.43,465.62,874.56,1010.0,1869.0,4061.3/    00002300
      DATA OK /.001/                                                    00002400
C***CHECK AGAINST INVALID DATA, USING A SERIES OF IF BLOCKS             00002500
      ERRFLG=.FALSE.                                                    00002600
      IF(IDYNT.NE.1.AND.IDYNT.NE.2) THEN                                00002700
          WRITE(6,*) '      INVALID DATA:  IDYNT  = ',IDYNT             00002800
          ERRFLG=.TRUE.                                                 00002900
      END IF                                                            00003000
      IF(ISTAB.LT.1.OR.ISTAB.GT.7) THEN                                 00003100
          WRITE(6,*) '      INVALID DATA:  ISTAB  = ',ISTAB             00003200
          ERRFLG=.TRUE.                                                 00003300
      END IF                                                            00003400
      IF(AMIX.LT.0.) THEN                                               00003500
          WRITE(6,*) '      INVALID DATA:  AMIX   = ',AMIX              00003600
          ERRFLG=.TRUE.                                                 00003700
      END IF                                                            00003800
      IF(U.LT.0.) THEN                                                  00003900
          WRITE(6,*) '      INVALID DATA:  U      = ',U                 00004000
          ERRFLG=.TRUE.                                                 00004100
      END IF                                                            00004200
      IF(ERRFLG) STOP                                                   00004300
C***CALCULATE "TEMPORARY" VALUES FROM INPUT DATA                        00004400
      ISTABT=ISTAB                                                      00004500
      IF(ISTABT.EQ.7) ISTABT=6                                          00004600
      AMIXT=AMIX                                                        00004700
      AMXMAX=5000./.797885                                              00004800
      IF(AMIXT.GT.AMXMAX) AMIXT=AMXMAX                                  00004900
```

```
C***SET LOWER LIMIT ON AMIXT, SINCE IT IS NOT USED IN STABLE CONDITIONS      00005000
      IF(AMIXT.LT.240.) AMIXT=240.                                           00005100
      UT=U                                                                   00005200
      IF(UT.LT.1.) UT=1.                                                     00005300
C***                                                                         00005400
C***CLIMATOLOGICAL DISPERSION MODEL (CDM) PORTION                            00005500
C***DETERMINE CRITICAL DOWNWIND DISTANCE, XCRIT                              00005600
C***FORTRAN 77 IF...THEN...ELSE USED TO FIND CRITICAL DOWNWIND DISTANCE      00005700
      IF(ISTABT.LE.4) THEN                                                   00005800
          ICOEFF=3                                                           00005900
          IF(ISTABT.EQ.3.AND.AMIXT.LT.338.5) ICOEFF=2                        00006000
C***     THIS STATEMENT MODIFIES CDM ACCORDING TO PASQUILL(1974)             00006100
          IF(IDYNT.EQ.1.AND.ISTABT.EQ.4) ICOEFF=1                            00006200
C***     .797885 IS CDM VALUE FOR SQRT(2./PI)                               00006300
          XCRIT=(.797885*AMIXT/ACOEFF(ICOEFF,ISTABT))                        00006400
     &          **(1./BCOEFF(ICOEFF,ISTABT))                                 00006500
      ELSE                                                                   00006600
          XCRIT=100000.                                                      00006700
      END IF                                                                 00006800
C***END FORTRAN 77 IF...THEN...ELSE                                          00006900
C***DETERMINE VIRTUAL DISTANCE (30 METERS VERTICAL DISPERSION), XMIN30       00007000
      IF(ISTABT.LE.3) XMIN30=XMINST(ISTABT)                                  00007100
      IF(ISTABT.EQ.4.AND.IDYNT.EQ.1) XMIN30=XMINST(4)                        00007200
      IF(ISTABT.EQ.4.AND.IDYNT.EQ.2) XMIN30=XMINST(5)                        00007300
      IF(ISTABT.GE.5) XMIN30=XMINST(ISTABT+1)                                00007400
C***INITIALIZE CONCENTRATION DUE TO UNIFORM AREA SOURCE, CONUAR               00007500
      CONUAR=0.                                                              00007600
C***CALCULATE PARTIAL CONCENTRATIONS AND ADD TO TOTAL (WITHIN DO LOOP)       00007700
C***THE DO LOOP INDEX, I, HELPS CONTROL DOWNWIND DISTANCE RANGE LIMITS       00007800
      DO 10 I=1,3                                                            00007900
          ICOEFF=I                                                           00008000
C***     THIS STATEMENT MODIFIES CDM ACCORDING TO PASQUILL(1974)             00008100
          IF(IDYNT.EQ.1.AND.ISTABT.EQ.4) ICOEFF=1                            00008200
C***     INITIALIZE PARTIAL CONCENTRATIONS, CON1 AND CON2                    00008300
          CON1=0.                                                            00008400
          CON2=0.                                                            00008500
C***     DETERMINE DOWNWIND DISTANCE RANGE LIMITS                            00008600
          XHIGH=XLIMIT(I+1)                                                  00008700
          IF(XMIN30.GE.XHIGH) GO TO 10                                       00008800
          IF(I.EQ.3) XHIGH=XHIGH+XMIN30                                      00008900
          XLOW=XLIMIT(I)                                                     00009000
          IF(XMIN30.GT.XLOW) XLOW=XMIN30                                     00009100
C***     NEXT TWO STATEMENTS REFERENCE FUNCTIONS                             00009200
          IF(XHIGH.GT.XCRIT) CON1=CRITGT(XHIGH,XLOW,XCRIT,AMIXT,UT,OK)       00009300
          IF(XLOW.LT.XCRIT) CON2=CRITLT(XHIGH,XLOW,XCRIT,ACOEFF,BCOEFF,      00009400
     &                                  ICOEFF,ISTABT,UT,OK)                 00009500
C***     END FUNCTION REFERENCES                                             00009600
          CONUAR=CONUAR+CON1+CON2                                            00009700
   10     CONTINUE                                                           00009800
```

```
C***                                                                    00009900
C***VENTILATION FACTOR (V. F.) PORTION                                  00010000
C***DETERMINE "TEMPORARY" MIXING HEIGHT FOR V. F. (NO CHANGE IF DAY)    00010100
      IF(IDYNT.EQ.2.AND.AMIXT.GT.600.) AMIXT=600.                       00010200
C***DETERMINE DEPTH OF "UNIFORM" SMOKE LAYER FOR BOX MODEL              00010300
      IF(ISTABT.LE.4) DPSMOK=AMIXT                                      00010400
      IF(ISTABT.EQ.5) DPSMOK=180.                                       00010500
      IF(ISTABT.EQ.6) DPSMOK=150.                                       00010600
C***CALCULATE AND ADD V. F. CONCENTRATION TO CDM CONCENTRATION          00010700
C***THIS CONCENTRATION IS WEIGHTED 50/50 BETWEEN V. F. AND CDM          00010800
      CONUAR=CONUAR+50./(UT*DPSMOK)                                     00010900
C***CALCULATE THE DISPERSION INDEX                                      00011000
      DINDHR=1./CONUAR                                                  00011100
      RETURN                                                            00011200
      END                                                               00011300


C***                                                                    00000100
C***FUNCTION DETERMINES CONCENTRATIONS DUE TO DISTANCES .GT. XCRIT      00000200
C***                                                                    00000300
      FUNCTION CRITGT(XHIGH,XLOW,XCRIT,AMIXT,UT,OK)                     00000400
C***DETERMINE DOWNWIND DISTANCE RANGE LIMITS FOR THIS CALCULATION       00000500
      XMAXGT=XHIGH                                                      00000600
      XMINGT=XLOW                                                       00000700
      IF(XMINGT.LT.XCRIT) XMINGT=XCRIT                                  00000800
C***CALCULATE PARTIAL CONCENTRATION                                     00000900
      CRITGT=OK*(XMAXGT-XMINGT)/(UT*AMIXT)                              00001000
      RETURN                                                            00001100
      END                                                               00001200


C***                                                                    00000100
C***FUNCTION DETERMINES CONCENTRATIONS DUE TO DISTANCES .LT. XCRIT      00000200
C***                                                                    00000300
      FUNCTION CRITLT(XHIGH,XLOW,XCRIT,ACOEFF,BCOEFF,ICOEFF,ISTABT,UT,  00000400
     &                OK)                                               00000500
      DIMENSION ACOEFF(3,6),BCOEFF(3,6)                                 00000600
C***DETERMINE DOWNWIND DISTANCE RANGE LIMITS FOR THIS CALCULATION       00000700
      XMAXLT=XHIGH                                                      00000800
      XMINLT=XLOW                                                       00000900
      IF(XMAXLT.GT.XCRIT) XMAXLT=XCRIT                                  00001000
C***CALCULATE PARTIAL CONCENTRATION                                     00001100
      BPOWER=1.-BCOEFF(ICOEFF,ISTABT)                                   00001200
      PRTOFT=.797885/(ACOEFF(ICOEFF,ISTABT)*BPOWER)                     00001300
      TINTGL=PRTOFT*(XMAXLT**BPOWER-XMINLT**BPOWER)                     00001400
      CRITLT=OK*TINTGL/UT                                               00001500
      RETURN                                                            00001600
      END                                                               00001700
```

Lavdas, Leonidas G.

An atmospheric dispersion index for prescribed burning. Res. Pap. SE-256. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1986. 33 pp.

A numerical index that estimates the atmosphere's capacity to disperse smoke from prescribed burning is described. The physical assumptions and mathematical development of the index are given in detail. A preliminary interpretation of dispersion index values is offered. A FORTRAN subroutine package for computing the index is included.

KEYWORDS: Smoke management, air pollution potential, ventilation factor, Gaussian dispersion, mesoscale air quality, atmospheric stability classes, area pollution sources.

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